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A STUDY OF THE NUMBER OF DOCTORATES CONFERRED BY AMERICAN UNIVERSITIES 1949-1953

Raymond M. Hughes[1]

Our American universities are now so large that it is very difficult to gain a comprehensive view of all the work being done. This is an attempt to aid the Deans of Graduate Schools in visualizing the magnitude of the work of their own graduate school in comparison with other graduate schools in the various fields.

It is also an effort to aid all interested in graduate work to secure a picture of the offerings in all fields in the United States at a time when the demands for graduate instruction to meet the needs of education, industry and business, and to compete with Russian advances in higher education and research, are very great.

Hitherto education in the United States has so far excelled that of other nations that we have had no problem of competition. Recently the great advances in Education in Russia, fully supported by the national budget, certainly raise the question whether Russia, in the next 25 or 50 years, will excel in numbers the United States in developing scientific leaders.

Since our development of graduate offerings is free and depends almost wholly on the demands of students and the initiative of individual faculty members, each institution should strive to attain its most useful growth and expansion.

Available annually since 1933 have been "Reports on Doctoral Dissertations Accepted by American Universities". This annual publication gives the title of each dissertation accepted during the preceding year for the doctorate and summarizes the number of degrees conferred by each institution in each recognized field.

"In order to avoid misinterpretations it must be made clear that the lists in this series are not limited to dissertations written for the Ph. D. degree, but that dissertations written for other kinds of doctoral degrees, e.g. in Education, Science, Jurisprudence, Canon Law and Theology, are included" p. XV, Vol. 22. This is especially confusing in Education where the number of Educ. D. is large.

Certainly the quality of graduate training offered cannot be judged by the number of Doctorates conferred. However, the number of degrees conferred is significant of the esteem of students for the institution, and the tables herein, supplemented by the judgment of an informed scholar in a particular field, will probably prove more reliable than the unsupported scholar's judgment, as all institutions leading in number of degrees are presented.

All degrees in the "Reports on Doctoral Dissertations" are here classified in 48 fields, based on the titles of the dissertations. The 48

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Table 1. 48 Fields given in "Doctoral Dissertations," with the 10 or more institutions

No. of degrees conferred 1954-55	1		2		3		4	
1400 Education	Columbia[a]	91.6	Stanford	61.0	NYU	59.4	Indiana	46.2
1150 Chemistry	Illinois	66.4	Ohio St.	51.4	Wisc.	48.2	Purdue	42.4
740 Psychology	NYU	44.8	Columbia	35.6	Chicago	28.4	Michigan	27.4
528 Physics	Calif.	34.8	MIT	28.6	Harvard	27.4	Columbia	20.0
478 Economics	Harvard	58.4	Columbia	31.0	Wisc.	26.6	Chicago	24.2
378 Engineering	MIT	34.8	Illinois	33.6	Purdue	23.4	Cal. Tech.	22.6
345 English Lit.	Harvard	27.9	Columbia	27.8	NYU	18.4	Yale	15.0
335 Biochemistry	Wisc.	35.4	Calif.	20.8	Minn.	14.8	Cornell	12.2
298 Bacteriology	Wisc.	23.2	Calif.	13.4	Penna.	12.2	Ohio St.	11.2
254 History	Columbia	27.0	Harvard	24.0	Calif.	14.4	Wisc.	13.2
249 Mathematics	Princeton	11.4	Chicago	10.0	Columbia	9.4	Harvard	8.6
			Michigan	10.0				
228 Sociology	Chicago	22.0	Columbia	17.6	Harvard	10.2	N. Car.	8.2
216 Agriculture	Wisc.	27.0	Cornell	18.2	Iowa St.	16.0	Mich. St.	13.6
190 Zoology	Michigan	18.0	Calif.	9.0	Cornell	8.6	Wisc.	8.2
167 Political Sci.	Harvard	22.0	Columbia	16.6	Chicago	14.4	Calif.	6.8
138 Religion	S. Bapt.	23.0	Catholic	21.8	Columbia	13.2	Yale	11.0
							SW Bapt.	11.0
131 Geology	Columbia	12.2	Wisc.	11.4	Princeton	7.2	Harvard	6.8
130 Botany	Calif.	10.6	Wisc.	8.8	Iowa St.	6.4	Harvard	5.8
			Michigan	8.8			Cornell	5.8
130 Physiology	Calif.	8.6	Illinois	8.2	Chicago	7.0	Iowa	6.0
130 Speech	Northw'n	16.4	Iowa	11.0	Wisc.	9.8	S. Calif.	8.6
119 Romance Languages	Columbia	18.8	Yale	9.6	Harvard	9.0	Princeton	5.4
100 Philosophy	Columbia	17.4	Catholic	10.6	Harvard	7.0	Chicago	5.4
					Yale	7.0		
99 Entomology	Cornell	11.4	Calif.	9.6	Illinois	6.8	Ohio St.	6.6
90 Pharmacology	Purdue	10.0	Wisc.	7.4	Chicago	4.8	Michigan	3.8
75 Metallurgy	MIT	15.0	Ohio St.	3.0	Purdue	2.2	Columbia	1.8
							Michigan	1.8
65 Genetics	Minn.	9.4	Calif.	7.4	Wisc.	7.0	Iowa St.	4.2
65 Horticulture	Cornell	12.4	Mich. St.	10.0	Ohio St.	6.8	Minn.	3.0
65 Medicine and Surgery	Wisc.	20.6	Minn.	11.2	Penna.	5.8	Chicago	4.8

[a] In 1949-50 and 1950-51 all doctorates in Education are listed under Columbia. For the following 3 years doctorates in Education are listed separately under Columbia and Columbia (Teachers College).

conferring the highest number of doctoral degrees on the average, 1949-54

5		6		7		8		9		10	
Ohio St.	37.4	S. Calif.	33.2	Harvard	31.4	Chicago	30.0	Pittsburg	29.0	Michigan	26.4
Columbia	37.4	Calif.	35.6	MIT	35.2	Michigan	27.2	Penn. St.	25.6	Iowa St.	25.2
Ohio St.	26.8	Iowa	25.0	Purdue	21.6	Minn.	20.2	Calif.	20.0	Pittsburg	16.6
Cornell	18.8	Illinois	16.6	Ohio St.	16.2	Chicago	15.6	Yale	15.0	Wisc.	14.6
Illinois	22.4	Cornell	19.8	Ohio St.	17.6	Calif.	14.8	Indiana	12.8	Iowa	12.6
Stanford	21.0	Michigan	18.8	Harvard	18.0	Wisc.	13.0	Cornell	12.4	Calif.	10.8
Penna.	13.8	Wisc.	12.4	Michigan	12.2	Chicago	11.4	Stanford N. Car.	10.0 10.0	Northw'n	8.8
Illinois	10.6	Purdue	9.2	Columbia	9.0	Iowa St.	8.8	Penn. St.	7.8	Chicago	7.4
Illinois	10.8	Iowa St. Mich. St.	10.6 10.6	Minn.	9.6	Cornell	8.8	Rutgers	7.4	Yale	7.0
Chicago	12.0	Yale Penna.	9.2 9.2	N. Car.	9.0	Stanford	8.6	Texas	8.2	Michigan	7.4
Calif.	8.4	Illinois	8.2	Wisc.	7.2	N. Car.	6.8	MIT NYU	6.6 6.6	Iowa St.	4.8
Cornell NYU	7.4 7.4	Wisc. Ohio St.	7.0 7.0	Penna.	6.0	Yale	5.6	S. Calif.	4.8	Catholic	3.8
Ohio St.	10.2	Purdue	10.0	Illinois	9.6	Minn.	9.2	Rutgers	9.0	Penn St. Missouri	7.2 7.2
Ohio St.	5.8	Chicago Illinois	4.8 4.8	Stanford Calif. LA	4.6 4.6	Iowa	4.4	Harvard	4.2	Penna.	3.8
Minn.	5.6	Wisc. Penna.	5.0 5.0	Princeton	4.8	Illinois	4.4	NYU Johns Hop.	4.2 1.0	Iowa Michigan	4.0 4.0
Chicago	9.6	Harvard	7.0	S. Calif.	6.8	Duke	4.6	Union	3.2	[b]Iowa	1.4-
Chicago	5.8	Stanford	5.4	MIT	5.2	Yale Calif. LA	5.0 5.0	Mich. St.	3.8	Minn. Johns Hop. Calif.	3.0 3.0 3.0
Columbia	5.2	Chicago	4.8	Michigan	4.6	Ohio St.	3.8	Iowa	3.6	Mich. St.	3.4
NYU	5.6	Minn.	5.2	Rochester	4.6	Ohio St. Harvard	3.0 3.0	Northw'n Indiana	2.6 2.6	Columbia	2.0
Michigan	6.4	Ohio St.	5.4	Stanford	3.0	Illinois Purdue	2.8 2.8	Columbia	2.2	Cornell Minn.	1.6 1.6
N. Car.	5.2	Wisc.	4.8	Iowa	4.6	Michigan	4.0	Stanford	3.6	Calif. Chicago	3.2 3.2
Cornell	3.4	Princeton	2.6	S. Calif.	2.2	Calif. LA	2.0	Michigan Wisc.	1.6 1.6	Calif. Penna.	1.4 1.4
Wisc.	5.2	Iowa St.	4.0	Minn.	3.0	Harvard Rutgers	2.6 2.6	Johns Hop. Chicago Mich. St. Maryland	1.0 1.0 1.0 1.0	Michigan	0.8
Minn. Rochester Maryland	3.6 3.6 3.6	Yale Ohio St.	3.2 3.2	Iowa	2.6	Calif.	1.4	Rutgers	2.0	Illinois	1.4
Calif.	1.6	Penna. Penn. St. Stanford Yale	1.4 1.4 1.4 1.4	Pittsburg	1.2	Illinois Harvard Minn.	1.0 1.0 1.0				
Cornell	4.0	Columbia	3.2	Cal. Tech. Indiana	2.2 2.2	Texas	1.0	Illinois Purdue	0.8 0.8	Chicago Johns Hop. Mich. St. NYU Northw'n	0.6 0.6 0.6 0.6 0.6
Purdue Maryland	2.8 2.8	Calif. LA	2.4	Rutgers	2.0	Illinois Iowa St.	1.8 1.8	Wisc.	1.2	Penn. St.	1.0
Harvard	3.2	Illinois	1.8	Calif.	1.4	Cornell	1.2	Ohio St. Purdue	0.8 0.8	Mich. St. Johns Hop. Rochester Northw'n	0.6 0.6 0.6 0.6

[b]Iowa University is the only institution listed which has no School of Divinity.

Continued

Table 1 (Cont.). 48 Fields given in "Doctoral Dissertations," with the 10 or more

No. of degrees conferred 1954-55								
62 Music	Rochester	9.4	Iowa	8.6	Michigan	3.0	Indiana	2.8
							S. Calif.	2.8
52 Geography	Chicago	5.6	Northw'n	3.6	Michigan	3.2	Calif.	2.0
49 International Law	Chicago	7.6	Harvard	3.4	Yale	3.0	Columbia	2.6
52 Paleontology	Calif.	1.4	Chicago	1.0	Columbia	0.8	Minn.	0.6
	Illinois	1.4	Wisc.	1.0	Yale	0.8		
					Harvard	0.8		
					Iowa	0.8		
44 Anthropology	Columbia	11.6	Harvard	5.4	Chicago	5.2	Calif.	4.6
40 Art and Archeology	Harvard	6.0	Columbia	3.4	Ohio St.	2.8	Princeton	1.8
					NYU	2.8	Iowa	1.8
40 Anatomy	Michigan	3.0	Columbia	2.0	Cornell	1.6	Chicago	1.2
			Minn.	2.0			NYU	1.2
							Northw'n	1.2
36 Classics	Harvard	3.6	Columbia	3.2	N. Car.	2.2	Illinois	1.8
							Princeton	1.8
							S. Bapt. Th.	1.8
30 German	Columbia	3.8	Yale	3.0	Harvard	2.2	Wisc.	2.0
					Michigan	2.2	Ohio St.	2.0
					NYU	2.2		
					Penna.	2.2		
19 Oriental Lit.	Columbia	3.2	Yale	2.4	Harvard	2.0	Princeton	1.2
			Johns Hop.	2.4	Chicago	2.0	Penna.	1.2
17 Astronomy	Chicago	3.4	Calif.	2.6	Harvard	2.4	Michigan	1.4
17 Public Health	Harvard	5.8	Johns Hop.	4.2	Yale	1.0	Rutgers	0.8
17 Geophysics	Cal. Tech.	2.2	Calif. LA	1.4	Harvard	1.0	Calif.	0.6
							Columbia	0.6
							MIT	0.6
							Penn. St.	0.6
17 East European Literature	Columbia	3.8	Harvard	3.0	Penna.	1.2	Calif.	0.6
							Cornell	0.6
							Yale	0.6
13 Law	Harvard	4.8	Columbia	4.2	NYU	3.2	Cornell	0.6
10 General Lit.	Columbia	1.8	Yale	1.0	Chicago	0.8	Harvard	0.6
			Indiana	1.0	Cornell	0.8		
8 Mineralogy	Penn. St.	2.6	Columbia	1.0	Illinois	0.6	Harvard	0.4
			Chicago	1.0			MIT	0.4
			Michigan	1.0				
6 Meteorology	MIT	2.8	Chicago	2.4	NYU	2.2	Calif. LA	2.0
8 Home Economics	Wisc.	1.0	Cornell	0.8	Iowa St.	0.6	Ohio St.	0.4
7 Library Science	Chicago	1.6	Columbia	0.6	Michigan	0.4		
			Illinois	0.6				

institutions conferring the highest number of doctoral degrees on the average, 1949-54

5		6		7		8		9		10	
Northw'n	2.6	Columbia	2.4	Harvard	2.2	Yale	1.4	Union	1.2	Calif. LA	0.8
		NYU	2.4			N. Car.	1.4				
Ohio St.	1.6	Wisc.	1.4	Johns Hop.	1.2	Illinois	1.0	Indiana	0.8	N. Car.	0.6
		Calif. LA	1.4					Harvard	0.8	Princeton	0.6
		Maryland	1.4					Iowa	0.8	Penna.	0.6
								Nebraska	0.8	Stanford	0.6
Princeton	1.8	Stanford	1.4	Wisc.	1.2	Calif.	1.0	Michigan	0.8	Johns Hop.	0.6
		Texas	1.4			NYU	1.0	Illinois	0.8	Minn.	0.6
						Northw'n	1.0	Calif. LA	0.8	Nebraska	0.6
								Duke	0.8		
Cornell	0.4										
Johns Hop.	0.4										
Michigan	0.4										
Princeton	0.4										
Stanford	0.4										
Yale	3.4	Northw'n	2.6	Cornell	2.0	Michigan	1.8	Indiana	1.2	Calif. LA	0.6
						Penna.	1.8				
Chicago	1.4	Minn.	0.8	Northw'n	0.6	Penna.	0.4				
Yale	1.4	Johns Hop.	0.8	Cornell	0.6	Duke	0.4				
				Wisc.	0.6						
				Michigan	0.6						
Rochester	1.0	Calif.	0.8	Iowa	0.6	Yale	0.4				
		Illinois	0.8	Indiana	0.6						
		Penna.	0.8	Stanford	0.6						
		Wisc.	0.8	Princeton	0.6						
Chicago	1.6	Calif.	1.2	Wisc.	1.0	Cornell	0.8	Penna.	0.6	Minn.	0.4
		Michigan	1.2	Johns Hop.	1.0	Ohio St.	0.8	Texas	0.6	NYU	0.4
		Yale	1.2	Catholic	1.0					Northw'n	0.4
										Pittsburgh	0.4
Johns Hop.	1.8	Northw'n	1.6	Chicago	1.4	Illinois	1.0	S. Calif.	0.8	Minn.	0.6
Calif.	1.8					Princeton	1.0	Texas	0.8	Indiana	0.6
Stanford	1.8					N. Car.	1.0	Iowa	0.8	Maryland	0.6
Calif.	0.8	S. Bap. Th.	0.6								
		SW Bap. Th.	0.6								
Princeton	1.2	Columbia	0.8	Iowa	0.4						
		Cal. Tech.	0.8	Penna.	0.4						
Michigan	0.6	Calif.	0.4								
		Wisc.	0.4								
		Iowa	0.4								
		N. Car.	0.4								
		Indiana	0.4								
Indiana	0.4										
Wisc.	0.2										
Iowa	0.2										
Wisc.	0.4										
NYU	0.4										
Penn. St.	0.8	Calif.	0.4								

Table 2. Tabulations of 37 major institutions in which the number of doctorates

Based on no. fields in each division		1		2		3		4	
Columbia	286	Education	40.6	Psychology	35.6	Religion	13.2	Physics	20.0
		English	27.8	Economics	31.0	Math.	9.4	Intern. Law	2.6
		History	27.0	Sociology	17.6	Paleontol.	0.8	Metallurgy	1.8
		Philosophy	17.4	Polit. Sci.	16.6			Geophysics	0.6
		Geology	12.2	Law	4.2				
		Anthropol.	11.6	Art & Arch.	3.4				
		Romance L.	9.6	Classics	3.2				
		German	3.8	Anatomy	2.0				
		E.Europ.L.	3.8	Mineralogy	1.0				
		Orient. L.	3.2	Libr. Sci.	0.6				
		Gen'l Lit.	1.8						
Harvard	248	Economics	58.4	History	24.0	Physics	27.4	Math.	8.6
		Polit. Sci.	22.0	Eng. Lit.	27.9	Sociology	10.2	Geology	6.8
		Art & Arch.	6.0	Anthropol.	5.4	Romance L.	9.0	Botany	5.8
		Pub. Health	5.8	Intern. Law	3.4	Philosophy	7.0	Gen'l Lit.	0.6
		Law	4.8	E.Europ.L.	3.0	Astronomy	2.4	Mineralogy	0.4
		Classics	3.6			German	2.2		
						Orient. L.	2.0		
						Geophysics	1.0		
						Paleontol.	0.8		
Chicago	228	Sociology	22.0	Math.	10.0	Psychology	28.4	Economics	24.2
		Intern. Law	7.6	Meteorol.	2.4	Polit. Sci.	14.4	Philosophy	5.4
		Geography	5.6	Paleontol.	1.0	Physiology	7.0	Med. & Surg.	4.8
		Astronomy	3.4	Mineralogy	1.0	Anthropol.	5.2	Anatomy	1.2
		Libr. Sci.	1.6			Pharmacol.	4.8		
						Orient. L.	2.0		
						Gen'l Lit.	0.8		
Wisconsin	218	Biochem.	35.4	Geology	11.4	Chemistry	48.2	History	13.2
		Agriculture	27.0	Botany	8.8	Economics	26.6	Zoology	8.2
		Bacteriol.	23.2	Pharmacol.	7.4	Speech	9.8	German	2.0
		Med. & Surg.	20.6	Paleontol.	1.0	Genetics	7.0		
		Home Econ.	1.0						
California	206	Physics	34.8	Biochem.	20.8	History	14.4	Polit. Sci.	6.8
		Botany	10.6	Bacteriol.	13.4			Geography	2.0
		Physiology	8.6	Entomol.	9.6			Anthropol.	4.6
		Paleontol.	1.4	Zoology	9.0			Geophysics	0.6
				Genetics	7.4			E.Europ.L.	0.6
				Astronomy	2.6				
Michigan	163	Zoology	18.0	Math.	10.0	Geography	3.2	Psychology	27.4
		Anatomy	3.0	Botany	8.8	Music	3.0	Pharmacol.	3.8
				Mineralogy	1.0	German	2.2	Metallurgy	1.8
						Libr. Sci.	0.4	Astronomy	1.4
Cornell	141	Horticult.	12.4	Agriculture	18.2	Zoology	8.6	Biochem.	12.2
		Entomol.	11.4	Home Econ.	0.8	Anatomy	1.6	Botany	5.8
						Gen'l Lit.	0.8	E.Europ.L.	0.6
								Law	0.6
Yale	138			Romance L.	9.6	Engl. Lit.	15.0	Religion	11.0
				German	3.0	Philosophy	7.0	E.Europ.L.	0.6
				Orient. L.	2.4	Intern. Law	3.0		
				Gen'l Lit.	1.0	Pub. Health	1.0		
						Paleontol.	0.8		
Illinois	140	Chemistry	66.4	Engineering	33.6	Entomol.	6.8	Classics	1.8
		Paleontol.	1.4	Physiology	8.2	Mineralogy	0.6		
				Libr. Sci.	0.6				

conferred was among the 10 highest in the United States

5	6	7	8	9	10
Chem. 37.4 Botany 5.2	Genetics 3.2 Music 2.4 Astron. 0.8	Biochem. 9.0		Speech 2.2	Physiol. 2.0
Medicine and Surg. 3.2	Religion 7.0	Education 31.4 Engr. 18.0 Music 2.2	Physiol. 3.0 Metall. 1.0	Zoology 4.2 Entomol. 2.6 Geogr. 0.8	
History 12.0 Religion 9.6 Geology 5.8 Art & Arch. 1.4 Classics 1.6	Zoology 4.8 Botany 4.8	German 1.4	Education 30.0 Physics 15.6 Engl. Lit. 11.4		Biochem. 7.4 Romance 3.2 Entomol. 1.0 Genetics 0.6
Entomol. 5.2 Gen'l Lit. 0.4 Law 0.2	Engl. Lit. 12.4 Sociology 7.0 Polit. Sci. 5.0 Rom. L. 4.8 Geogr. 1.4 Anatomy 0.8 Pub. Hlth. 0.4	English 12.4 Math. 7.2 Intl. Law 1.2 Classics 1.0 Art and Arch. 0.6	Engr. 13.0	Philosophy 1.6 Horticult. 1.2	Physics 14.6 Religion 0.8
Math. 8.4 German 1.8 Metallurgy 1.6 Orient. L. 0.8	Chem. 35.6 Classics 1.2 Anatomy 0.8 Meteorol. 0.4 Pub. Hlth. 0.4	Medicine and Surg. 1.4	Econ. 14.8 Pharm. 1.4 Intl. Law 1.0	Psychol. 20.0	Engr. 10.8 Rom. L. 3.2 Geology 3.0 Philos. 1.4 Music 0.6
Speech 6.4 Pub. Hlth. 0.6 Paleontol. 0.4	Engr. 18.8 Classics 1.2 Entomol. 0.8	English 12.2 Botany 4.6 Art & Arch. 0.6	Chem. 27.2 Rom. L. 4.0 Anthropol. 1.8	Philos. 1.6 Intl. Law 0.8	Education 26.4 History 7.4 Polit. Sci. 4.0
Physics 18.8 Sociology 7.4 Genetics 4.0 Philos. 3.4 Paleontol. 0.4	Econ. 19.8	Art & Arch. 0.6	Bacteriol. 8.8 Med. and Surg. 1.2 Classics 0.8	Engr. 12.4	Speech 1.6
Anthropol. 3.4 Art and Arch. 1.4	History 9.2 Pharm. 3.2 Metallurgy 1.4 Classics 1.2		Sociology 5.6 Geology 5.0 Music 1.4 Anatomy 0.4	Physics 15.0	Bacteriol. 7.0
Econ. 22.4 Biochem. 10.6 Bacteriol. 10.8	Physics 16.6 Math. 8.2 Zoology 4.8 Med. and Surg. 1.8 Anatomy 0.8	Agricult. 9.6	Polit. Sci. 4.4 Speech 2.8 Horticul. 1.8 Metallurgy 1.0 Geogr. 1.0 German 1.0	Genetics 0.8 Intl. Law 0.8	Pharm. 1.4

Continued

Table 2 (Cont.). Tabulations of 37 major institutions in which the number of doctorates

Based on no. fields In each division		1		2		3		4	
Ohio State	126			Chemistry	51.4	Horticult.	6.8	Bacteriol.	11.2
				Metallurgy	3.0	Art & Arch.	2.8	Entomol.	6.6
								German	2.0
								Home Ec.	0.4
NYU	95	Psychology	44.8			Education	59.4	English	14.4
						Art & Arch.	2.8	Anatomy	1.2
						Law	3.2		
						German	2.2		
						Meteorol.	2.2		
Minnesota	93	Genetics	9.4	Med. & Surg.	11.2	Biochem.	14.8	Horticult.	3.0
				Anatomy	2.0			Paleontol.	0.6
Pennsylvania	84					Bacteriol.	12.2	Orient. L.	1.2
						Med. & Surg.	5.8		
						German	2.2		
						E. Europ. L.	1.2		
Iowa	82			Speech	11.0	Paleontol.	0.8	Physiology	6.0
				Music	8.6			Art and Arch.	1.8
Princeton	87	Math.	11.4			Geology	7.2	Romance L.	5.4
								Art & Arch.	1.8
								Classics	1.8
								Orient. L.	1.2
MIT	63	Engineering	34.8	Physics	28.6			Geophysics	0.6
		Metallurgy	15.6					Mineralogy	0.4
		Meteorol.	2.8						
Stanford	62			Education	61.0				
Purdue	60	Pharmacol.	10.0			Engineering	23.4	Chemistry	42.4
						Metallurgy	2.2		
Northwestern	55	Speech	16.4	Geography	3.6			Anatomy	1.2
Indiana	51			Gen'l Lit.	1.0			Education	46.2
								Music	2.8
Iowa State	48					Agriculture	16.0	Genetics	4.2
						Botany	6.4		
						Home Ec.	0.6		
N. Carolina	42					Classics	2.2	Sociology	8.2
Penn. State	42	Mineralogy	2.6			Home Ec.	0.6	Geophysics	0.6
California (Los Angeles)	41			Geophysics	1.4			Meteorol.	2.0
Johns Hopkins	41			Pub. Health	4.2				
Southern Calif.	31							Speech	8.6
								Music	2.8
Mich. State	27			Horticult.	10.0			Agriculture	13.6

conferred was among the highest in the United States

Education	37.4	Sociology	7.9	Econ.	17.6	Botany	3.8	Med. and			
Psychol.	26.8	Speech	5.4	Physics	16.2	Physiol.	3.0	Surg.	0.8		
Agricult.	10.2	Pharm.	3.2			Classics	0.8				
Zoology	5.8										
Geogr.	1.6										
Sociology	7.4	Music	2.4			Intl. Law	1.0	Math.	6.6	Genetics	0.6
Physiol.	5.6							Polit. Sci.	4.2	Classics	0.4
Gen'l Lit.	0.4										
Polit. Sci.	5.6	Physiol.	5.2	Bacteriol.	9.6	Psychol.	20.2			Geology	3.0
Pharm.	3.6	Art and				Agricult.	9.2			Speech	1.6
		Arch.	0.8			Entomol.	3.0			Intl. Law	0.6
						Metallurgy	1.0			German	0.6
										Classics	0.4
English	13.8	History	9.2	Sociology	6.0	Anthropol.	1.8	Classics	0.6	Zoology	3.8
		Polit. Sci.	5.0	Astron.	0.4	Art and				Philos.	1.4
		Metallurgy	1.4			Arch.	0.4			Geogr.	0.6
		Anatomy	0.8								
Law	0.2	Psychol.	25.0	Romance	4.6	Zoology	4.4	Botany	3.6	Econ.	12.6
		Pub. Hlth.	0.4	Pharm.	2.6			Geogr.	0.8	Polit. Sci.	4.0
				Astron.	0.4			German	0.8	Religion	1.4
Intl. Law	1.8	Philos.	2.6	Polit. Sci.	4.8	German	1.0			Geogr.	0.6
Astron.	1.2			Anatomy	0.6						
Paleontol.	0.4										
				Chem.	35.2			Math.	6.6		
				Geology	5.2						
Engr.	21.0	Geology	5.4	Zoology	4.6	History	8.6	English	10.0	Geogr.	0.6
Paleontol.	0.4	Metallurgy	1.4	Speech	3.0			Romance	3.6		
German	1.8	Intl. Law	1.4	Anatomy	0.6						
Horticult.	2.8	Agricult.	10.0	Psychol.	21.6	Speech	2.8	Genetics	0.8		
		Biochem.	9.2					Med.&Surg.	0.8		
Music	2.6	Anthropol.	2.6	Art and		Intl. Law	1.0	Physiol.	2.6	English	8.8
		German	1.6	Arch.	0.6					Genetics	0.6
										Med.&Surg.	0.6
										Classics	0.4
E.Eur. L.	0.4	Pub. Hlth.	0.4	Genetics	2.2			Econ.	12.8	German	0.6
				Anatomy	0.6			Physiol.	2.6		
								Geogr.	0.8		
								Anthropol.	1.2		
		Bacteriol.	10.6	Entomol.	4.0	Biochem.	8.8			Chem.	25.2
						Horticult.	1.8			Math.	4.8
Romance	5.2	Pub. Hlth.	0.4	History	9.0	Math.	6.8	English	10.0	Geogr.	0.6
						Music	1.4				
						German	1.0				
Meteorol.	0.8	Metallurgy	1.4					Chem.	25.6	Agricult.	7.2
								Biochem.	7.8	Horticult.	1.0
		Horticult.	2.4	Zoology	4.6	Geology	5.0	Intl. Law	0.8	Anthrop.	0.6
		Geography	1.4			Philos.	2.0	Music	0.8		
German	1.8	Art and		Geography	1.2			Polit. Sci.	1.0	Geology	3.0
Paleontol.	0.4	Arch.	0.8	Classics	1.0					Entomol.	1.0
										Genetics	0.6
										Intl. Law	0.6
										Med. & Sur.	0.6
		Education	33.2	Religion	6.8			Sociology	4.8		
				Philos.	2.2			German	0.8		
		Bacteriol.	10.6					Geology	3.8	Botany	3.4
										Entomol.	1.0
										Genetics	0.6
										Med.&Sur.	0.6

Continued

Table 2 (Cont.). Tabulations of 37 major institutions in which the number of doctorates

Based on no. fields in each division							
Rochester	27	Music	9.4				
Cal. Inst. Tech.	26	Geophysics	2.2			Engineering	22.6
Catholic	23			Religion	21.6		
				Philosophy	10.6		
Rutgers	19					Pub. Health	0.8
S. Bapt. Th.	17	Religion	2.3			Classics	1.8
Texas	14						
Maryland	13						
Pittsburgh	10						
SW Bapt. Th.	7					Religion	11.0
Duke	6						

Table 3. Number of institutions conferring doctorates and total doctorates conferred 1954-55

	Institutions	No. of degrees		Institutions	No. of degrees		Institutions	No. of degrees
Chemistry	94	1150	Philosophy	36	100	Art & Arch.	20	40
Education	79	1409	Romance Lan.	35	119	Classics	20	36
Physics	76	528	Geology	35	131	Horticulture	17	65
Psychology	74	740	Entomology	34	99	Anthropology	15	44
Biochemistry	74	335	Religion	34	138	Paleontology	12	18
Bacteriology	66	298	Agriculture	31	216	Oriental Lan.	12	19
English	63	345	Med. & Surg.	30	65	Law	10	13
Mathematics	62	249	Pharmacology	27	90	Astronomy	10	17
History	62	254	Speech	26	130	Geophysics	10	17
Economics	59	478	Anatomy	26	40	Public Health	9	17
Zoology	54	190	Metallurgy	25	75	E. Europ. Lan.	7	17
Sociology	51	228	Music	24	62	General Lit.	7	10
Engineering	48	378	Geography	23	52	Library Sci.	6	7
Botany	44	130	Internatl. Law	23	49	Home Ec.	7	8
Physiology	42	130	German	22	30	Mineralogy	7	8
Political Sci.	42	167	Genetics	21	65	Meteorology	4	6

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Anatomy 1.0 Pharm. 3.6		Physiol. 4.6			Med. and Surg. 1.2
	Astron. 0.8	Genetics 2.2			
		Classics 1.0			
		Horticult. 2.0		Agricult. 9.0 Bacteriol. 7.4 Entomol. 2.6	
	Intl. Law 1.4		Genetics 1.0	History 8.2 German 0.8 Classics 0.6	
Horticult. 2.8	Geography 1.4				Entomol. 6.0 German 0.6
		Metallurgy 1.2		Education 29.0 Religion 1.0	Psychol. 16.6 Classics 0.4
			Religion 4.6 Art & Arch. 0.4		

Table 4. Doctorates conferred and fields covered 1954-55

	Doctorates	No. fields		Doctorates	No. fields		Doctorates	No. fields
Wisconsin	399	33	Michigan	180	38	Pittsburgh	126	20
Calif. Berkeley	317	36	Mass. Inst. Tech.	171	12	Iowa State	116	15
New York U.	303	28	Texas	170	24	Princeton	101	20
Columbia	299	36	Stanford	168	27	North Carolina	87	23
Harvard	299	37	Iowa	162	27	Johns Hopkins	82	22
Ohio State	262	29	Penn State	159	24	Maryland	79	19
Chicago	240	31	Pennsylvania	154	32	Catholic	77	17
Cornell	233	36	Northwestern	147	24	Calif. Inst. Tech.	75	11
Illinois	233	28	Indiana	138	23	Duke	67	19
Minnesota	222	31	Michigan State	137	20	Rochester	54	11
Purdue	201	18	Calif. Los Angeles	135	23	Rutgers	52	13
Yale	197	33	Southern California	134	19	S. W. Baptist Theol.	15	4
						Southern Bapt. Th.	15	2
							5862	

Table 5. Fields in which the demand for doctorates is greatest

	PhD degrees conferred 1954-55		PhD degrees conferred 1954-55
Greatest demand:		Less demand:	
Education	1409	Zoölogy	190
Chemistry	1150	Political Science	167
Psychology	740	Religion	138
Physics	528	Geology	131
Economics	478	Botany	130
Engineering	378	Physiology	130
English Literature	345	Speech	130
Biochemistry	335	Romance Languages	119
Bacteriology	298	Philosophy	100
History	254	Entomology	99
Mathematics	249	Pharmacology	90
Sociology	228	Metallurgy	75
Agriculture	216		
Lesser demand:		Least demand:	
Genetics	65	Oriental Languages	19
Horticulture	65	Paleontology	18
Medicine and Surgery	65	Astronomy	17
Music	62	Geophysics	17
Geography	52	Public Health	17
International Law	49	East European Lang.	17
Anthropology	44	Law	13
Anatomy	40	General Literature	10
Art and Architecture	40	Mineralogy	8
Classics	36	Home Economics	8
German Literature	30	Library Science	7
		Meteorology	6

fields there recognized are accepted for use in these studies. A survey of all fields in all universities was deemed impracticable. These studies include in each field only the 10 institutions conferring the largest number of degrees.

Of the 8812 doctorates conferred in 1954-55, 6006, or 68 per cent, were conferred by these 37 institutions. The remaining 97 institutions conferred 2806 or 32 per cent.

The number of fields in which the Doctorate was conferred varied from 11 to 38. Ten conferred 31-38; 5, 25-29; 10, 20-24; 8, 11-19.

Table 1 contains a study of the leading institutions in each of the 48 fields. The fields are arranged in the order of the number of doctorates conferred in each field in 1954-55.

Among the first fields 11 conferred from 7 to 26 doctorates in the 10th place, so it is clear that a number of important institutions are

omitted from this part of the table. In the remaining 37 fields we can feel confident that no institutions doing important work are omitted.

Table 2 is based on Table 1. Thirty-seven major graduate schools were selected. The first column in this table lists the fields in which the institutions listed on the left rank first in the average number of degrees conferred in the five years 1949-50 to 1953-54. The second column lists the fields in which it ranks second, and so on.

The institutions are listed according to the numbers on the right margin. These numbers are obtained by multiplying the number of fields in the first column by 10, the number of fields in the second column by 9, and so on to the number in the tenth column by 1. The numbers thus obtained for each institution are added together, giving the number that places the institution. This ranking is for convenience and because it gives a clearer picture. It is not a basis for judging the quality of the degrees. This point is perhaps best shown by the places of the Massachusetts Institute of Technology, 15th, and California Institute of Technology, 27th, while both are certainly known to rank among the best in their limited fields.

Various facts emerge as one studies these tables.

The eastern and oldest universities confer more doctorates in languages, humanities and social sciences and fewer in the other sciences. On the other hand, the universities in the western and central parts of the country, which are of more recent establishment, confer many more doctorates in the sciences and fewer in languages, humanities, and social sciences. To verify this compare in Table 2, Columbia and Harvard with Wisconsin and California.

As we study the fields in which the greatest number of degrees are conferred we note that of the 15 in which more than 150 degrees were conferred, 8 were in the sciences, engineering and mathematics; 6 are in social sciences, education and psychology; 1 is in English.

The cost of graduate instruction is high, not only because those capable of directing research are high-salaried men and can only direct the research of a small number of candidates for the doctorate, but also because the great majority of graduate students must be paid, in fellowships or as teaching or research assistants, a large part or all of their expenses. This latter item could be covered by Federal fellowships to the great advantage of the universities.

The question of how many doctor's research and dissertations can be directed at one time by one professor is important. Many feel that the maximum number should be between 5 and 10, and should never exceed 15 for the ablest professors. While perhaps the demand for the doctorate will not be great enough to raise this question in more than 8 or 10 fields, and only in a small number of institutions, it remains a serious question when it is raised. In Education, where the greatest demand for the doctorate is evident, the situation is met in part by awarding the Doctor of Education degree (as well as the Ph.D. degree) with minor research requirement.

While it does not appear in this study, it is certainly most discouraging to those concerned about science, to note the steadily decreasing proportion of high school graduates who have high school training in mathematics, chemistry, and physics. The decline in required courses

in these subjects and the growing tendency of high school students to elect easy subjects are having serious effects.

Table 3 gives the number of institutions conferring the doctorate and the number of doctorates conferred in each field in 1954-55. This information is particularly valuable when introduction of the doctorate in a new field is being considered by an institution.

Table 4 gives the number of doctorates conferred by each of the 37 institutions in 1954-55 and the number of fields in which doctorates were conferred.

For an institution planning to enter the field of graduate work, Table 5 will show in what fields there is greatest demand for work leading to the doctorate.

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IOWA ASCOMYCETES II. DIAPORTHACEAE : VALSEAE[1]

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ABSTRACT

The members of the section Valseae of the Diaporthaceae from Iowa are described and illustrated. Included are 22 species of Valsa on 21 host genera, 3 species of Valsaria on 10 hosts, 1 species of Endothia, 3 species of Fenestella on 4 host genera and a single species of Valsella. A key to the species is included.

The Section Valseae of the Diaporthaceae was chosen as the second group of Iowa Ascomycetes to be catalogued in this series (Gilman and Tiffany, 1951). The Iowa collections are found in the genera Valsa, Valsella, Endothia, Valsaria, and Fenestella. This arrangement follows the intensive study of this group of fungi by Wehmeyer (1926) except that the separation of the genus Leucostoma from that of Valsa is not accepted. Distinctions in stromatic structure as pointed out by Wehmeyer are present but scarcely such as to warrant generic distinction. Further, Fenestella has been added to the section since its stromatic structure as well as the structure of the centrum of the perithecium and the morphology of the ascus indicate a close relationship to the other genera included. The conidial phase of Fenestella with its multiloculate pycnidium and small allantoid spores characteristic of the genus Cytospora is additional evidence of this relationship.

Wehmeyer divided the stromatic Sphaeriales into two families Allantosphaeriaceae with asci having "long persistent stalks, resulting in a persistent definite hymenial layer of asci" and the Diaporthaceae with asci "with short, evanescent stalks," resulting in free asci and ascospores within the perithecium. Within the Diaporthaceae the Valseae are differentiated by their characteristic multiloculate pycnidium, as contrasted with the simple pycnidium of the Eudiaportheae.

The Valseae are primarily associated with woody plants where they commonly fruit on cankered areas of the twigs and branches. They are facultative parasites gaining extrance to their hosts through wounds or tissues injured by frost or cold or shading. Once established they may develop into adjacent areas of the host producing severe damage. Mention of the destructive impact of Endothia parasitica (Murr.) P. J. and H. W. Anders on the chestnut forests of the eastern United States (Shear et al. 1917) is sufficient to indicate their potentiality.

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In Iowa the Valseae are chiefly found on tree species that are subject to winter injury, particularly that type caused by exposure to a warm spring period in which the dormancy is broken, followed by freezing temperatures that kill these tender reactivated tissues.

The first important collections of these fungi were made in Iowa by E.W. Holway and reported by Ellis and Everhart (1892). Following these collections little has been reported. In 1936, Gilman, McNew, and Davis (1936) made a brief report on canker fungi from Iowa but the detailed report on Valseae was not published. *Valsa pini* on Pinus and *Valsa nivea* on Populus were the only species listed. Several species of Cytospora, the conidial stage of Valsa in many cases, were reported, however, indicating that the members of this genus were widespread in the state. These collections were preserved and the Valseae are included as part of this report.

In addition to our own collections we have had access to the Holway collections in the Iowa State College Herbarium and the Herbarium of the New York Botanical Garden, as well as the collections in the Herbarium of the State University of Iowa. We acknowledge the courtesy of Dr. Donald P. Rogers for the former and Dr. G. W. Martin for the latter. Further, the material in the Mycological Collection of the United States Department of Agriculture at Beltsville, Maryland, was made available to us by Dr. John Stevenson and his staff. Thanks to this generous assistance, the material herein listed represents a fairly complete report of the Iowa material.

In summary, the genus Valsa is represented by 22 species on 21 genera of hosts; Valsaria by 3 species on 10 host genera, Fenestella by 3 species on 4 host genera and single species of Endothia and Valsella, respectively. The close approximation between the number of species of Valsa observed and the number of host genera upon which they occurred is not indicative of a host specificity in any broad sense. Certain species such as *Valsa ambiens* have a wide host range, Pyrus, Morus, Ulmus, Celtis, and Betula species, while others, as *Valsa menispermi* seem restricted. The points of distinction between species of fungi in these genera are small and judgments as to which characteristics are the more determining must be made. In general, we have considered the spore size of less significance than its shape as determined by the ratio of its length:diameter. The structure of the stroma, the relative development of the disc and the arrangement of the necks of the ostioles whether circinate or scattered and the color of the disc were regarded as important characteristics. The length of the necks of the ostioles was given minor weight.

Key to the Iowa Species of Valseae

a. Asci 4-8 spored.
  b. Ascospores one-celled, allantoid. . . . . **Valsa**
    c. Ectostromata scarcely delimited, stroma usually with a circumscribing line.
      d. Ascospores more than 12 microns long. . . 1. *V. cincta*
      dd. Ascospores less than 12 microns long.

e. Ascospores 9-12 microns long.
f. Ostioles grouped in center of disk. 2. _V_. _translucens_
ff. Ostioles scattered over disk. 3. _V_. _leucostoma_
ee. Ascospores 6-9 microns long.
f. Stromata scattered; ascospores 2-2.5 microns wide. . . . . 4. _V_. _nivea_
ff. Stromata seriately arranged; ascospores 1.25-1.5 microns wide. 5. _V_. _caryigena_
cc. Ectostromata definitely differentiated truncate cones, stroma usually without a circumscribing line.
d. Ascospores more than 12 microns long.
e. Ascospores narrow, 2-2.5 microns wide. . . . . 6. _V_. _grisea_
ee. Ascospores 3- 6 microns wide.
f. Ascospores 2.5-4 microns wide.
g. Perithecia many.
h. Disk obliterated. . . . . 7. _V_. _clausa_
hh. Disk present, perithecia circinate. . . . . 8. _V_. _salicina_
gg. Perithecia few.
h. Ascospores 12-20 x 3-4.5 microns. . . . . 9. _V_. _pauperata_
hh. Ascospores not over 14 microns long. . . . . 10. _V_. _saccharina_
ff. Ascospores more than 4 microns wide.
g. Ascospores up to 18 microns long.
h. Disks gray. . . . . . . 11. _V_. _leucostomoides_
hh. Disks brown. . . . . 12. _V_. _fraxinina_
gg. Ascospores more than 18 microns long.
h. Ascospores 14-23 x 3-5 microns. . . . . 13. _V_. _ambiens_
hh. Ascospores 15-20 x 4-6 microns. . . . . 14. _V_. _menispermi_
dd. Ascospores less than 12 microns long.
e. Ascospores 8-12 microns long.
f. Ascospores narrow, 1.5-2 microns wide.
g. Ostioles scattered over disk. . 15. _V_. _vitigera_
gg. Ostioles circinately arranged on disk. . . . . 16. _V_. _sordida_
f. Ascospores wider, 2-2.5 microns wide. . . . . 17. _V_. _decorticans_
ee. Ascospores 5- 9 microns long.
f. Disk conical.
g. Ostioles circinately arranged, ascospores narrow. . . . . . 18. _V_. _lutescens_
gg. Ostioles not circinately arranged, ascospores wider. . . . . . . 19. _V_. _modesta_
ff. Disk flat.
g. On deciduous trees. . . . . 20 _V_. _ceratophora_
gg. On coniferous trees.

h. Stromata raised surrounding disk. 21. V. pini
hh. Stromata flat, not raised surrounding disk. . . . . . . 22. V. abietis
bb. Ascospores septate.
c. Ascospores two-celled.
d. Ascospores hyaline. . . . . Endothia
e. Single species treated. . . . . . . 1. E. parasitica
dd. Ascospores dark. . . . . Valsaria
e. Ascospores 7–10 microns wide.
f. Apex of stromata tawny yellow. . 1. V. exasperans
ff. Apex of stromata dark, not tawny yellow. . . . . 2. V. insitiva
ee. Ascospores 3–4 microns wide. . . . 3. V. moroides
cc. Ascospores muriformly divided. . . . . Fenestella
d. Ascospores more than 10 microns wide. . . 1. F. vestita
dd. Ascospores less than 10 microns wide.
e. Ascospores 18–20 x 9–10.5 microns. . 2. F. rostrata
ee. Ascospores 12–16 x 7–8 microns. . . 3. F. ulmicola
aa. Asci polysporous. . . . . Valsella
b. Single species treated. . . . . 1. V. melastoma

Valsa Fr.

Stromata cortical; perithecia immersed in the bark, more or less distinctly circinate and lying in a single layer; ostioles entire, converging to the center and mostly united in a small erumpent disk; asci sessile, clavate-cylindrical, with 4–8 ascospores; ascospores allantoid, hyaline, one-celled.

1. Valsa cincta Fr. (Figs. 1–5)

Stromata scattered, strongly convex or obtusely conical, 2-3 mm in diameter, formed of the slightly altered inner bark, enclosed in a faint, black circumscribing line in cross-section; perithecia in a single layer, circinate, 1–15 in a stroma, globose to subangular, more than 1/3 mm in diameter, attenuated into very slender, converging necks with rather large black ostioles, around a central pore in a convex whitish disk; asci clavate, subsessile, 50–60 x 9–12 microns; ascospores biseriate, allantoid, hyaline, curved, 12–20 x 3.5–4 microns.

On Crataegus sp. Ames, May 1954, J. C. Gilman; March 1955, R. M. Lewis.

On Prunus padus L. Ames, April 26, 1955, R. M. Lewis; May 6, 1955, R. M. Lewis.

On Robinia pseudo-acacia L. Ames, April 12, 1955, R. M. Lewis.

2. Valsa translucens De Not. (Figs. 93–96)

Stromata gregarious, conical or hemispherical, 1/2 mm in diameter, perithecia 2–8 in a stroma, monostichous, globose, minute with slender necks and punctiform ostioles erumpent in the center of the small whitish disk; asci clavate or oblong, sessile, 8-spored, 40-44 x 8 microns; ascospores conglobate, allantoid, curved, hyaline, 9–14 x 2 microns.

Conidia allantoid, 4-5 x 1 microns.

On Populus sp. Ames, May 1955, R. M. Lewis.

3. Valsa leucostoma (Pers.) Fr. (Figs. 6-10) cf. Ell. N.A.F. 173.

Stromata strongly convex, 2-3 mm in diam., scattered irregularly, sometimes confluent, finely granular and whitish within; disk erumpent through short cracks in the epidermis, white, dotted with black mouths of ostioles; perithecia 4-10 in a stroma, globose, small, with necks slender and inordinately erumpent over the white disk; asci fusoid-clavate, subsessile, 35-45 x 7-8 microns; ascospores biseriate, allantoid, hyaline, slightly curved, 9-12 x 2-2.5 microns.

On Prunus serotina Ehrh. Ames, April 1955, R. M. Lewis.

On Prunus sp. J.A. Parrish.

On Pyrus ioensis (Wood) Bailey. Ames, January 25, 1955, R. M. Lewis.

On Pyrus malus L. Ames, April 17, 1955, MacWithey; May 4, 1949, P. Hoffman; August 1954, L. H. Tiffany and R. M. Lewis.

4. Valsa nivea (Hoff.) Fr. (Figs. 11-15) cf. Ell. N.A.F. 869, N.A.F. 2nd Ser. 2120.

Stromata scattered, white within, erumpent by a whitish disk, 1-2 mm across; perithecia, 4-10 in a stroma, circinate, globose, small, with slender necks ending in subglobose black punctiform ostioles circinate about the margin of the white disk; asci clavate, subsessile, 35-45 x 5-6 microns, 8- or 4-spored; ascospores allantoid, hyaline, slightly curved, 7-9 x 1.25-1.5 microns. Conidia allantoid, 6 x 1 microns, in reddish cirrhi.

On Populus grandidentata Michx. Boone, May 4, 1942, T.E. Brooks; Cedar Falls, J.A. Parrish; Iowa City, January 7, 1939, J.A. Parrish, G.W. Martin; Ames, 1955.

On Populus tremuloides Michx. Iowa City, March 12, 1939, G. W. Martin; Macbride No. 1385.

On Populus sp. Iowa, J. A. Parrish.

5. Valsa caryigena Berk. and Curt. (Figs. 16-19) cf. Ell. N.A.F. 867

Stromata orbicular at base, 1-1.5 mm in diameter, convex-conical, whitish within, raising the bark into distinct pustules, mostly seriately arranged, and pierced at the apex with a small dirty-white disk; perithecia in a single crowded layer at bottom or stroma, small, less than 0.25 mm in diameter, necks converging, their short black rounded ostioles soon obliterating the disk, leaving a white margin, but not much exserted; asci clavate, subsessile, 25-30 x 5 microns; ascospores, biseriate, allantoid, not strongly curved, hyaline, 6.5 x 1.5 microns. Closely allied to V. praestans Berk. and Curt.

On Carya sp. Decorah, May 1892, E. W. D. Holway; Cedar Falls, J. A. Parrish; Ames, September 30, 1955, L.H. Tiffany.

6. Valsa grisea Pk. (Figs. 20-23)

Stromata small; perithecia 4-15 in a stroma, with necks converging in a small (less than 1 mm), orbicular grayish to brownish disk with circinate black, punctiform ostioles; asci clavate, 50-55 x 7-8 microns;

ascospores subbiseriate, allantoid, hyaline, 10–13 x 2–2.5 microns.

On Fraxinus sp. Iowa, J. A. Parrish

Differs from V. fraxinina by its narrower spores and the presence of the gray brown dusty disk. Ellis and Everhart (1892) question these distinctions.

7. Valsa clausa Cke. and Ell. (Figs. 56–59) cf. Ell. N.A.F. 870

Stromata cortical, brown inside, 1–1.5 mm in diameter, depressed conical; perithecia 4–8 (up to 12–15) buried in lower part of stroma, 1–3.5 mm in diameter, subcircinate, with converging necks and obtuse, rough, black ostioles; asci clavate, p. sp. 40–45 x 6–7 microns; ascospores subbiseriate, allantoid, slightly curved, hyaline, 14–18 x 3–4 microns.

Conidia allantoid, minute, 3–4 x 1 microns.

On Quercus spp. Ames, February 1955, R.M. Lewis; November 10, 1955, R. M. Lewis; Boone, August 1955, L. H. Tiffany.

8. Valsa salicina (Pers.) Fr. (Figs. 52–55) cf. Ell. and Evrht, N.A.F. 2d Ser. 1951.

Stromata thickly scattered, depressed conical, truncate, with small whitish disk; perithecia, 6–12 in a stroma, circinating, with short slender necks ending in minute black, globose ostioles, erumpent around the margin of the disk; asci narrow-oblong or clavate, subsessile 4–8 spored, 40–65 x 7–8 microns; ascospores allantoid, hyaline, slightly curved, 12–18 x 2.5–4 microns (in 8-spored asci), 20–30 x 5–7 microns (in 4-spored asci).

On Salix sp. Iowa, J.A. Parrish (spores 22 x 6.5-7 microns); Ames, fall, 1954, R. M. Lewis; Ames, May 1955, L. H. Tiffany.

9. Valsa pauperata Curt. and Ell. (Figs. 97–100) cf. Ell. and Evrht. N.A.F. 2nd Ser. 1571.

Stromata numerous, subseriate, only slightly raising the bark; perithecia 2–4 in a stroma, subglobose, black, 1/3–1/2 mm in diam., necks decumbent and converging; asci clavate, p. sp. 60–70 x 8–10 microns; ascospores crowded, biseriate, allantoid, slightly curved, hyaline, 12-20 x 3–4.5 microns. Pycnidia, conical, multilocular; conidia allantoid, hyaline, 5–6 x 1 microns.

On Acer saccharinum L. Ames, April 20, 1955, R. M. Lewis.

10. Valsa saccharina Rehm (Figs. 60–63) Ann. Mycol. 10:540. 1912.

Stromata scattered, 2 mm in diameter, longitudinally confluent; perithecia, 10–15 in a stroma, globose, monostichous, 15 mm in diameter, black, with slender necks terminating in papilliform ostioles, scattered over a whitish disk; asci clavate, 8-spored, 30-35 x 8-9 microns; ascospores allantoid, hyaline 10-14 x 2.5-3, 2-3 ranked; paraphyses filiform.

On Acer saccharinum L. Ames, June 2, 1955, L. H. Tiffany.

11. Valsa leucostomoides Pk. (Figs. 64–66)

Stromata numerous, small, piercing the epidermis with an orbicular white or grayish disk; perithecia 2–6 or more per stroma with necks converging to black punctiform ostioles in the center of disk; asci clavate

or subfusoid, 49–50 x 8.5–10 microns; ascospores crowded, allantoid, hyaline, 12–18 x 4–5 microns.

On Pyrus sp. Ames, February 1955, R. M. Lewis.

Differs from V. leucostoma by absence of black circumscribing line around the stromata.

12. Valsa fraxinina Pk. (Figs. 89-92)

Stromata few; perithecia small, about 3 in each stroma, circinate with small, punctiform, black ostioles; asci subclavate, 50–60 x 8 microns; ascospores allantoid, subsessile, hyaline, 12–17 x 4–5 microns.

On Fraxinus pennsylvanica var. lanceolata (Borkh.) Sarg. Ames, April 5, 1955, R. M. Lewis; Kanawha, August 6, 1955, R. M. Lewis; Ames, October 12, 1955, L. H. Tiffany.

13. Valsa ambiens (Pers.) Fr. (Figs. 67–72) cf. Ell. N.A.F. 868.

Stromata numerous and generally thickly scattered, orbicular or elliptical at base, 1.5–3 mm broad, obtusely conical above, distinctly pustulate-prominent, covered by the closely adherent epidermis which is pierced by the erumpent disk or stellately cleft; perithecia 4–20 (mostly 6–10), subcircinate in the unaltered substance of the inner bark, about 0.5 mm in diam., mostly not crowded, necks slender, decumbent, with large, depressed-spherical, black ostioles, irregularly arranged, crowded and obliterating the disk; asci 40–55 x 12–15 microns, 4-8 spored, with a slender stipe-like base 30-35 microns long; ascospores conglomerate or subbiserate, allantoid, hyaline, slightly curved, obtuse, 14–24 x 3–5 microns in the 8-spored asci, in the 4-spored asci, 24–36 x 5–8 microns.

On Betula sp. Ames, April 1955, R. M. Lewis.

On Celtis occidentalis L. Ames, R. M. Lewis.

On Fraxinus sp. Ames, October 13, 1955, L. H. Tiffany.

On Morus rubra L. Ames, November 18, 1954, R. M. Lewis.

On Pyrus coronaria L. Iowa (NYBG).

On Pyrus malus L. Ames, April 1948, G. L. McNew.

On dead apple limbs, Decorah, April 29, 1892, E. W. D. Holway.

On Ribes floridum L'Her. Decorah, May 10, 1892, E. W. Holway (NYBG); (ISC).

On Rosa sp. Decorah, May 3, 1892, E. W. D. Holway (4-spored) (NYBG).

On Ulmus americana L. Ames, April 7, 1955, L. H. Tiffany; April 1955, R. M. Lewis; October 10, 1955, L.H. Tiffany; Iowa, J.A. Parrish; Ames, September 23, 1955, R. M. Lewis; Ames, October 10, 1955, L. H. Tiffany.

On Ulmus fulva Michx. Ames, 1955.

14. Valsa menispermi Ell. and Holw. (Figs. 24–27)

Stromata scattered, cortical, without circumscribing line; perithecia 6–10 per stroma, 0.25 mm in diameter, with short necks, circinately erumpent on the margin of the brown circular disk with black punctiform ostioles; asci clavate, 70 x 12 microns; ascospores crowded, allantoid, yellowish, slightly curved, 15–20 x 4–6 microns.

On Menispermum canadense L. Decorah 1883, Holway. (NYBG); (ISC).

15. Valsa vitigera Cke. (Figs. 28-31)

Stromata subcuticular, scattered, small; perithecia 3-6, about 1/3 mm in diameter with short necks terminating in the short conical ostioles erumpent in the center of the disk; asci clavate, p. sp. 40 x 6-7 microns; ascospores biseriate, allantoid, slightly curved, hyaline 8–10 x 1.5–2 microns. Conidia allantoid, hyaline, 4 x 1 microns.

On Parthenocissus quinquefolia (L.) Planch. Ames, January 11, 1955, R. M. Lewis.

16. Valsa sordida Nits. (Figs. 32-35)

Stromata thickly scattered, 2–3 mm in diameter, perithecia 6–12 in a stroma, subcircinate, globose or subcompressed, 1/3–1/2 mm in diameter with short neck erumpent around the margin of a grayish to brownish disk; asci clavate p. sp. 40-45 x 8 microns with stipe of 10-15 microns; ascospores subbiseriate, allantoid, slightly curved, 8–10 x 1.5 microns. Conidia allantoid, 4 x 1 microns in yellow cirrhi.

On Populus tremuloides Michx. Decorah, September 12, 1892, E. W. D. Holway.

On Populus sp. Decorah, E. W. D. Holway (Ell. and Ev. N. A. F. 1186) (NYBG); Iowa, E. W. D. Holway (NYBG); Boone, July 1955, L. H. Tiffany.

On Salix sp. Ames, April 20, 1955, H. S. MacWithey; Iowa, J. A. Parrish, T. H. Macbride.

17. Valsa decorticans Fr. (Figs. 36-39) cf. Ell. N. A. F. 496

Stromata orbicular or oval, depressed-conical, rather large, brown to black, with erumpent disk; perithecia, 6–20 in a stroma, not deeply buried, monostichous, globose or angular from pressure, with moderately long necks; ostioles exserted, slender, cylindrical, black, shining around an orbicular or elliptical disk; asci narrow oblong or clavate, sessile, 45–50 x 6 microns; ascospores conglobate, allantoid, slightly curved, hyaline, 10–12 x 2.5 microns. Conidia allantoid 4 x 1 microns.

On Acer platanoides L. Ames, June 21, 1955, L. H. Tiffany.

On Acer saccharum Marsh. Ames, December 2, 1954, R. M. Lewis; Ames, May 1955.

On Pyrus sp. Iowa, J. A. Parrish.

18. Valsa lutescens Ell. (Figs. 40–43) cf. Ell. N. A. F. 876.

Stromata thickly scattered, conical, dark brown inside, about 0.5 mm broad at base, not circumscribed; perithecia 10–20 in a stroma, subcircinate, small (1/3 mm or less), necks converging, slender, short cylindrical, subcoriaceous, erumpent around tobacco-brown disk; asci lanceolate-clavate, 3-5 x 5-6 microns; ascospores, subbiseriate, allantoid, hyaline, 5–7 x 1.5 microns. Conidia allantoid, hyaline 4–5 x 1 microns.

On Quercus sp. Ames, March 17, 1955, R. M. Lewis.

19. Valsa modesta (Schw.) Stevenson (Figs. 116–119)

Stromata nearly free in the inner bark, erumpent through the fissured epidermis by a dark brown disk; ostiola black, subprominent, densely crowded, cylindric-conical, imbedded in a cinereous matrix; asci 35 x 5 microns, ascospores biseriate, hyaline, 5–7 x 1.5–2 microns.

On Ulmus americana L. Ames, September 1955, R. M. Lewis.

20. Valsa ceratophora Tul. (Figs. 44-47) cf. Ell. N.A.F. 496, 864.

Stromata scattered, often standing close together but not confluent, orbicular or elliptical, depressed-hemispherical to conical, brown outside and staining the adjacent bark the same color; perithecia 5-20 in a stroma, crowded globose, small; ostioles more or less elongated, slender, cylindrical, united at their bases with their tips spreading; asci narrow-clavate, sessile, 32-40 x 4-5 microns; ascospores biseriate, allantoid, straight or slightly curved, hyaline, 6-8 x 1.5-2 microns.

On Carya ovata (Mill.) K. Koch. Ames, April 9, 1955, R. M. Lewis; Iowa, T. H. Macbride, No. 1386.

On Acer saccharum Marsh. Ames, September 16, 1955, L. H. Tiffany; Ames, October 17, 1955, R. M. Lewis.

On Ulmus americana L. Ames, August 1955, L. H. Tiffany.

On Juglans nigra L. Ames, July 18, 1955, L. H. Tiffany.

21. Valsa pini (A. and S.) Fr. (Figs. 73-76)

Stromata scattered or subgregarious, hemispherical, 1.5-2.5 mm in diam., perithecia small, 20-30 in a stroma, globose, with short necks converging to the center; asci narrow clavate, sessile, 25-30 x 5-6 microns; ascospores irregularly crowded, allantoid, slightly curved, hyaline, 6-9 x 1.5 microns. Conidia 4 x 1 microns, in yellow cirrhi.

On Pinus resinosa Art. Keosauqua, October 1954, W. Eslyn.

On Pinus strobus L. Ames: October 27, 1954, L. H. Tiffany and R. M. Lewis, September 23, 1954, J.C. Gilman; Iowa, Conservation Corps Collection No. 242.

On Pinus sylvestris L. Iowa Conservation Corps Collection No. 276.

On coniferous wood. Scranton, May 3, 1924, K. Gilmore, H. Mehalson and J. H. Miller.

22. Valsa abietis Fr. (Figs. 48-51) cf. Ell. N.A.F. 174.

Stromata irregularly scattered, depressed-conoid, small, covered by the subpustulate-elevated epidermis; perithecia, 5-15 in a stroma, small, globose or angular from pressure, buried in the unaltered substance of the bark; ostioles black, densely crowded, fasciculate with short cylindrical necks piercing the host epidermis; asci narrow-clavate, sessile, 25-32 x 5-6 microns; ascospores irregularly crowded, allantoid slightly curved, hyaline, 6-9 x 1.25-1.5 microns.

Pycnidia multilocular, narrowed above and erumpent by a single ostiole; conidia slender, one-celled, hyaline, 3 x 1 microns.

On Thuja occidentalis L. Iowa, J. A. Parrish.

Endothia Fr.

Stromata innate-erumpent, yellow; perithecia sunken, black, monostichous with long necks; asci fusoid, aparaphysate, 8-spored; ascospores short fusiform, hyaline, 1-septate.

1. Endothia parasitica (Murr.) P.J. and H.W. Anders. (Figs. 77-79)
Stromata corticular, slightly erumpent to truncate conical, gregarious, 0.5 x 1 mm in diameter; perithecia dark, globose to flask-shaped, 5-50 in a stroma, 300-400 microns in diameter, in one to three layers, with slender necks terminating in acute ostioles; asci oblong-elliptical to subclavate, sessile, 30-60 x 7-9 microns; ascospores irregularly biseriate, ellipsoid, one septate, constricted at the septum, hyaline, 7-11 x 3.5-5 microns. Conidia in irregular pycnidia 100 x 300 microns in diameter, 3-5 x 1.5-2 microns, oblong to cylindrical, pale yellowish in mass.
On Castanea dentata (Marsh.) Bork. Osage, 1927, Archer (Survey 1383)

Valsaria Ces. and De Not.

Stromata variable, valsiform or effused, usually covered by the epidermis; perithecia in one or more layers; asci mostly 8-spored, paraphysate; ascospores oblong elliptical, uniseptate, brown.

1. Valsaria exasperans (Gerard) Ell. and Ev. (Figs. 80-82) cf. Ell. N.A.F. 493
Stromata scattered or seriately confluent, orbicular to oblong, 1.5-2 mm high, subcarnose and dirty blackish or yellowish brown within, with tawny yellow apices erumpent and closely embraced by the epidermis; perithecia polystichous, subglobose, about 1/3 mm in diameter, coriaceous, black with cylindrical necks ending in black, rough conic-hemispherical ostioles; asci cylindrical, short stipitate, paraphysate, p. sp. 80-100 x 10 microns; ascospores uniseriate, oblong-elliptical, uniseptate, constricted at the septum, with rounded ends, deep reddish-brown, 14-16 x 9-10 microns.
On Acer sp. Story Co., November 2, 1941, McLaughlan.
On Populus sp. Decorah, May 4, 1882, E.W.D. Holway.
On Ulmus americana L. Ames, July 30, 1936, J.C. Gilman; Ames, 1955.

2. Valsaria insitiva Ces. and De Not. (Figs. 83-85) cf. Ell. N.A.F. 170
Stromata scattered, variable; dull black outside and light tobacco-brown within; perithecia 1/3 mm in diam.; deeply sunken, ovate to flask-shaped, with long, slender necks ending in subcircinate, short-conical papilliform ostioles; asci cylindrical, short-stipitate, paraphysate; ascospores uniseriate, oblong-elliptical, uniseptate, constricted at the septum, dark brown, rounded at the ends, 12-20 x 7-10 microns.
On Amorpha fruticosa L. Decorah, May 1882, E.W.D. Holway.
On Celastrus scandens L. Decorah, June 4, 1893, E.W.D. Holway.
On Gleditschia tricanthos L. Ames· November 14, 1913, J.P. Anderson; May 4, 1955, R.M. Lewis; Cambridge, Winter 1954, W. Eslyn; Iowa: Conservation Corp Collection No. 750.
On Pyrus malus L. Iowa City, April 9, 1933, G. W. Martin.
On Quercus alba L. Iowa City, G. W. Martin.
On Quercus rubra L. Iowa, Conservation Corps Collection No. 163.
On Quercus sp. Decorah, June 28, 1884, Holway.

3. Valsaria moroides (Cke. and Pk.) Sacc. (Figs. 86-88)

Stromata pulvinate, buried in the scarcely altered substance of the bark, suborbicular or elliptical, 2-4 mm long, with faint circumscribing line; perithecia 6-15 in a stroma, small (1/3 mm or less), black with short necks terminating in papilliform ostioles scattered over the disk; asci cylindrical, short-stipitate, 75-80 x 4 microns, paraphysate; ascospores uniseriate, slightly curved, one-septate, brown, 12-15 x 3-4 microns.

On Alnus sp. Decorah, May 30, 1892, E.W.D. Holway.

On Carpinus carolinana Walt. Decorah, June 1893, E.W.D. Holway.

Fenestella Tul.

Stromata and perithecia as in Valsa; asci cylindrical, 4-8 spored; ascospores uniseriate, oblong to elliptical, muriform, yellow brown.

1. Fenestella vestita Fr. (Figs. 105-108)

Stromata suborbicular, 2-3 mm in diameter with large tuberculiform disk; perithecia, 8-15 in a stroma, irregularly crowded, 1/2 mm in diameter, globose or angular with cylindrical necks convergent to the black papilliform ostioles, not exserted; asci cylindrical, 120-150 x 12-15 microns (p. sp. 80-100 microns long) with filiform paraphyses; ascospores uniseriate, elliptical, olive-brown, 3-5 septate and muriformly divided, scarcely constricted at the septa, 12-20 x 10-12 microns, (19-25 x 10-12 microns, 20-26 x 10-14 microns).

On Ailanthus altissima (Mill.) Swingle. Ames, April 10, 1941, W.H. Bragonier.

On Caragana sp. Ames, December 1954, R. M. Lewis; Ames, March 20, 1955, R. M. Lewis.

2. Fenestella rostrata (Fckl.) Sacc. (Figs. 109-111)

Stromata scattered; perithecia, 2-6 in a stroma, globose-conic, densely packed, large, 1 mm in diameter, with necks terminating in black exserted ostioles, rarely disposed in a circle; asci stipitate, cylindrical, 8-spored, 160 x 4 microns; ascospores obliquely uniseriate, oblong-ovate, 5-septate and muriformly divided, constricted at the septa, dark, 18-20 x 9-10.5 microns; paraphyses filiform multiguttulate; conidia in conical multiloculate pycnidia, one-celled, allantoid, 4 x 1 microns, in orange red cirrhi.

On Berberis thunbergii DC. Ames, April 1955, R. M. Lewis.

3. Fenestella ulmicola Ell. and Ev. (Figs. 112-115)

Stroma orbicular, convex, about 0.5 cm diameter, closely covered by the epidermis, which is raised into a broad pustule pierced by the minute black disk; perithecia 6-12, circinate, 0.5-0.75 mm in diameter, ovate-globose; necks conic-papilliform or convex; disk slightly raised above epidermis. Asci cylindrical, 110-120 x 12 microns; filiform paraphyses; ascospores uniseriate, oblong-elliptical, 5-septate and muriformly divided, brown, 12-16 x 7-8 microns.

On Ulmus americana L. Kanawha, August 12, 1955, R. M. Lewis.

Valsella Fckl.

Stromata valsoid, cortical, generally limited by a black, circumscribing line; ostiole entire (not sulcate); disk generally pale; asci sessile, polysporous; ascospores allantoid, hyaline, one-celled; pycnidia when present pluriloculate; conidia allantoid, hyaline, one-celled.

1. Valsella melastoma (Fr.) Sacc. (Figs. 101-104)
Stromata conical, more or less protuberant, about 1 mm in diameter; disk orbicular or subelliptical, minute, at first whitish-cinerous, becoming brown; perithecia 2-6, subcircinate, subspheroid, rather large, necks short, slender, terminating in minute, rounded, black, crowded ostioles; asci clavate-cylindrical, 30-50 x 6 microns; ascospores conglobate, allantoid, slightly curved, 4-7 x 1 microns.

On Pyrus malus L. Ames, July 15, 1942, J.C. Gilman.

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Pinus strobus
  Valsa pini

Pinus sylvestris
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  Valsa nivea
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Pyrus ioensis
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  Valsa modesta
  Valsaria exasperans
  Fenestella ulmicola

Ulmus fulva
  Valsa ambiens

Vitis sp.
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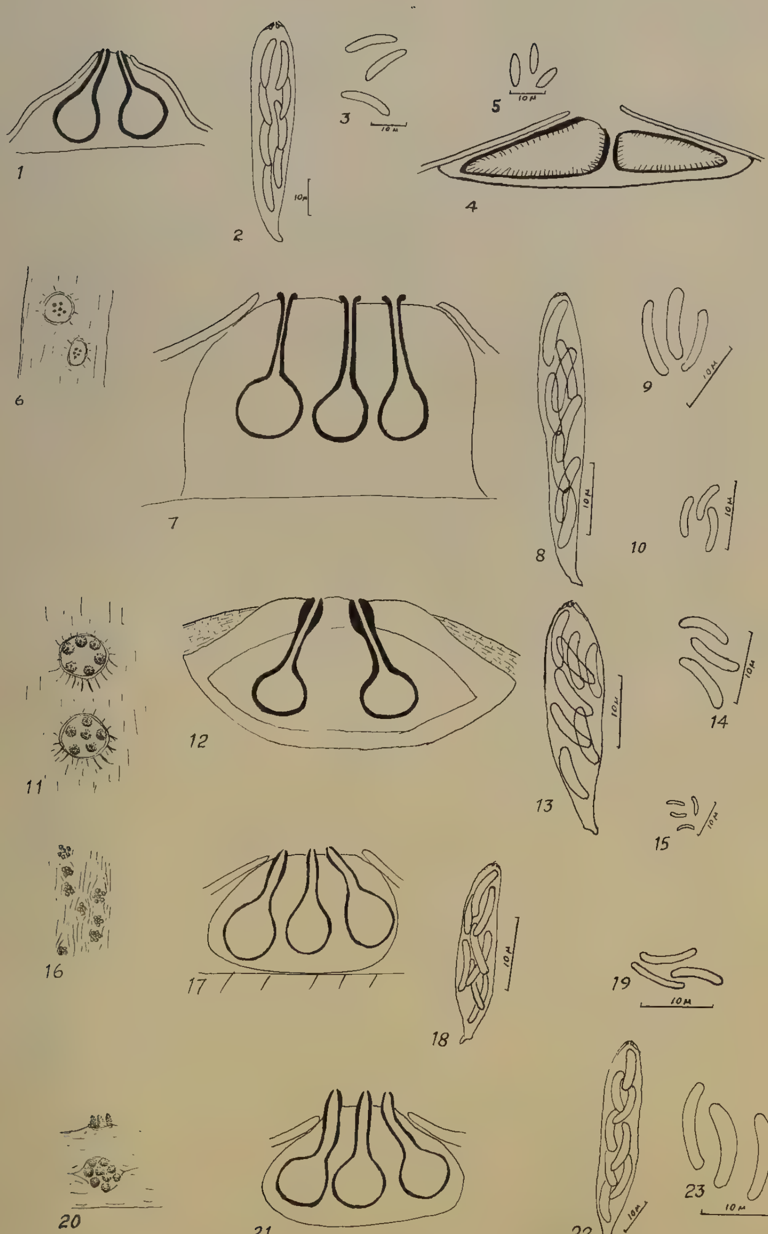
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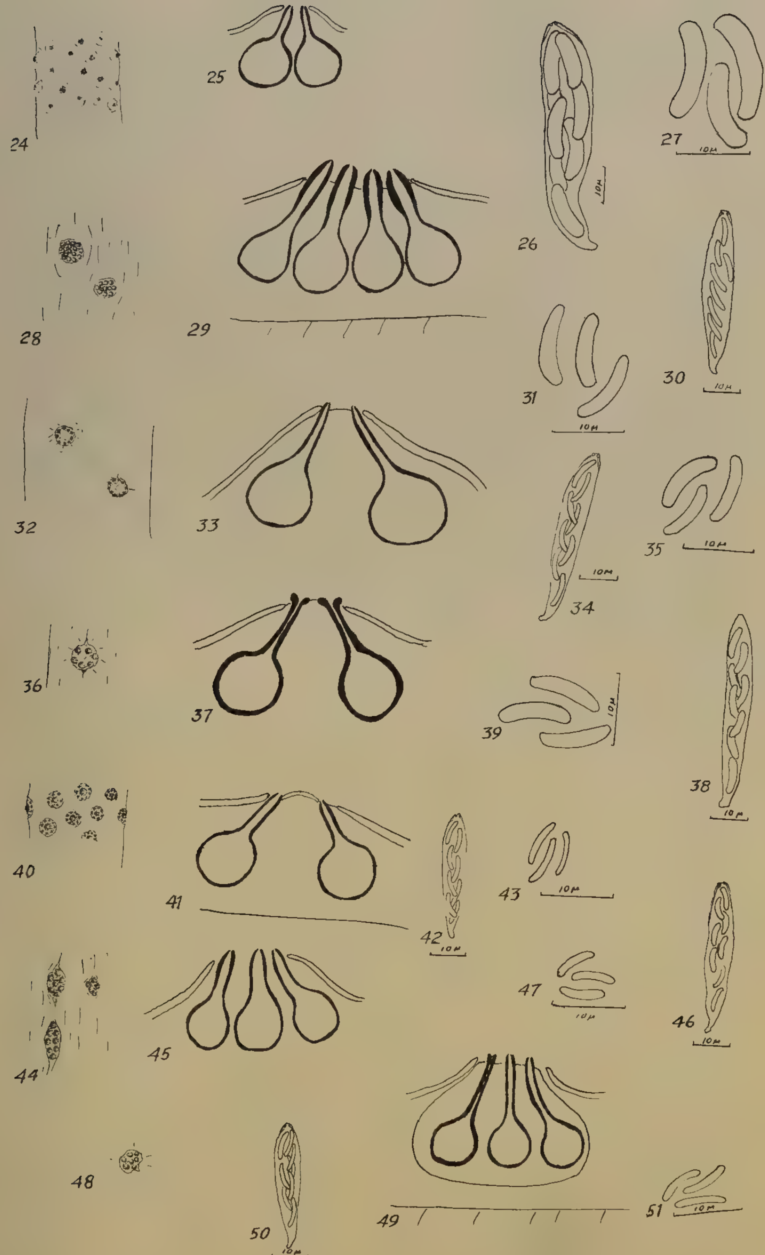
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PLATE 3

Figs. 52-55. Valsa salicina
52. Habit sketch 53. Stroma 54. Ascus 55. Ascospores

Figs. 56-59. Valsa clausa
56. Habit sketch 57. Stroma 58. Ascus 59. Ascospores

Figs. 60-63. Valsa saccharina
60. Habit sketch 61. Stroma 62. Ascus 63. Ascospores

Figs. 64-66. Valsa leucostomoides
64. Stroma 65. Ascus 66. Ascospores

Figs. 67-72. Valsa ambiens
67. Habit sketch 68. Stroma 69. Ascus 70. Ascospores
71. Pycnidium 72. Conidia

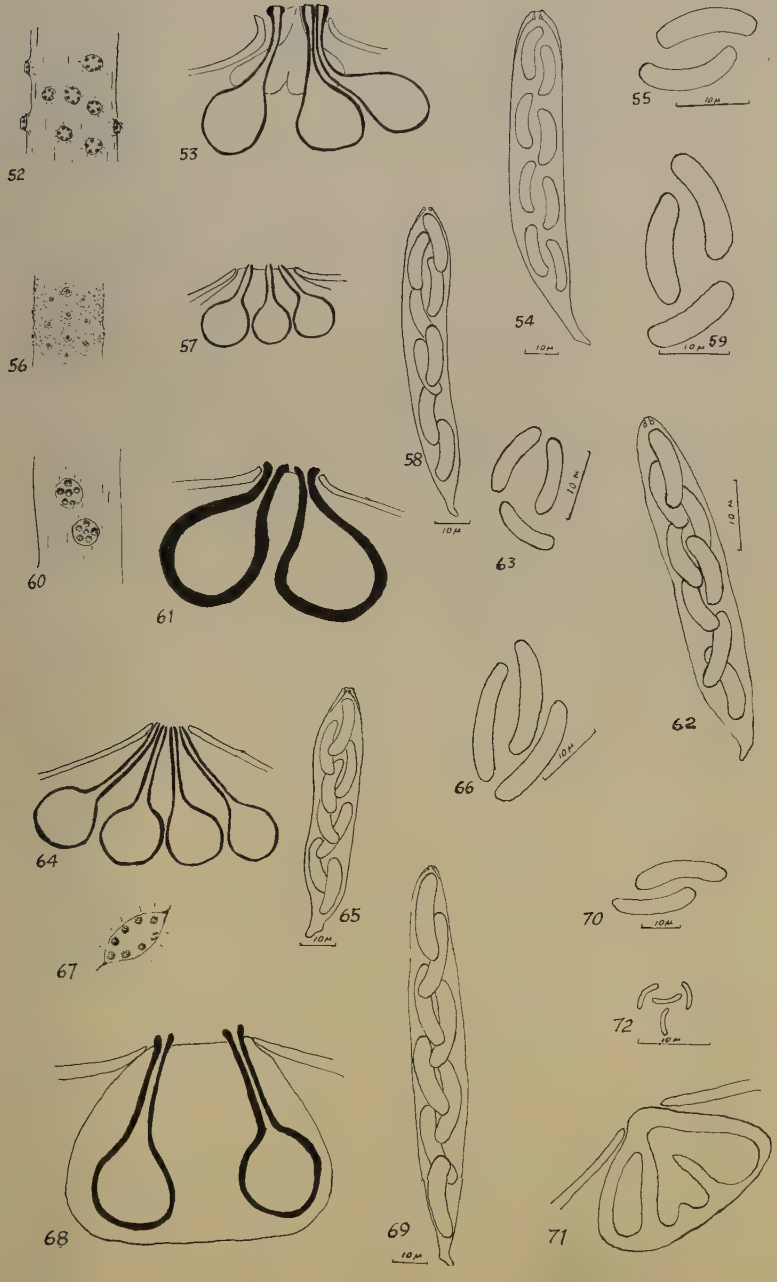
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PLATE 4

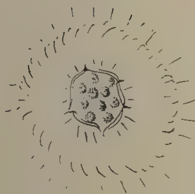
Figs. 73-76. Valsa pini
73. Habit sketch 74. Stroma 75. Ascus 76. Ascospores

Figs. 77-79. Endothia parasitica
77. Stroma 78. Ascus 79. Ascospores

Figs. 80-82. Valsaria exasperans
80. Habit sketch 81. Stroma 82. Ascus and ascospores

Figs. 83-85. Valsaria insitiva
83. Habit sketch 84. Stroma 85. Ascus and ascospores

Figs. 86-88. Valsaria moroides
86. Habit sketch 87. Stroma 88. Ascus and ascospores



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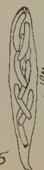

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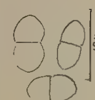

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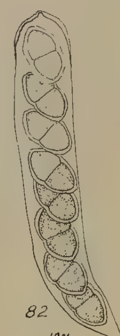

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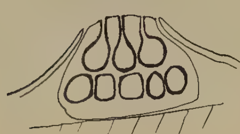

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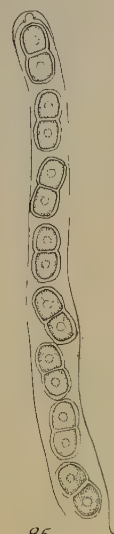

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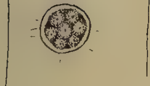

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PLATE 5

Figs. 89-92. Valsa fraxinina
89. Habit sketch 90. Stroma 91. Ascus 92. Ascospores

Figs. 93-96. Valsa translucens
93. Habit sketch 94. Stroma 95. Ascus 96. Ascospores

Figs. 97-100. Valsa pauperata
97. Habit sketch 98. Stroma 99. Ascus 100. Ascospores

Figs. 101-104. Valsella melastoma
101. Habit sketch 102. Stroma 102 Ascus 104. Ascospores

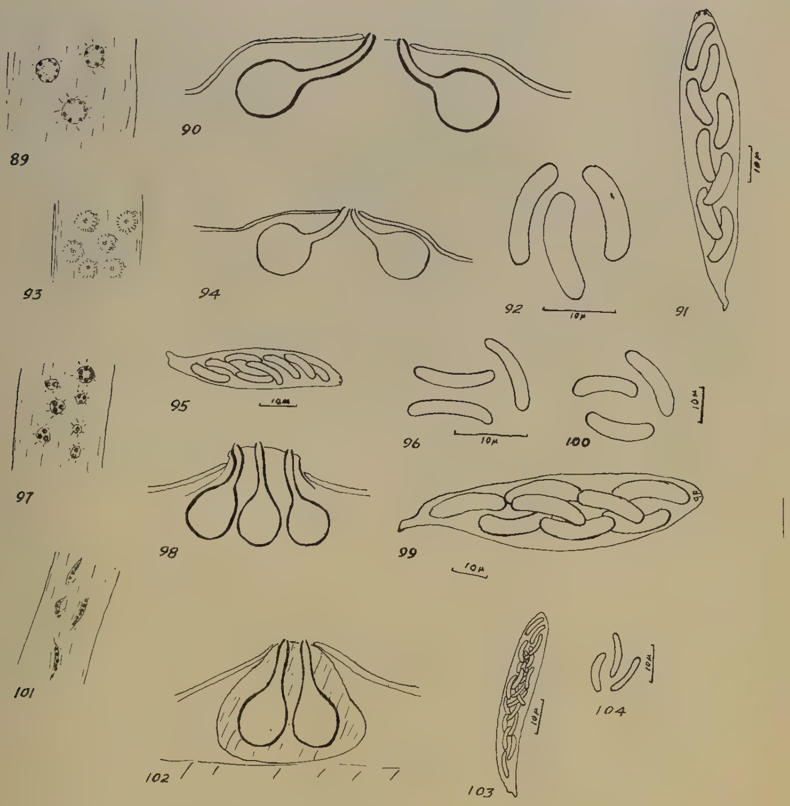

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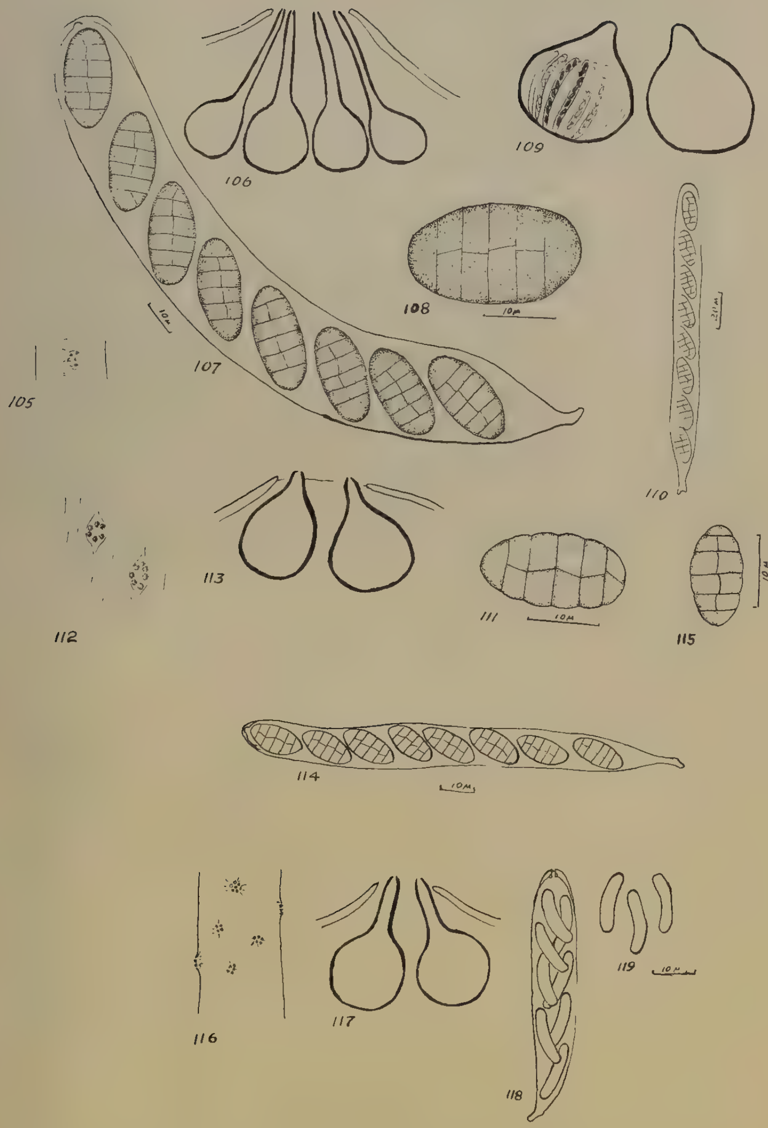
PLATE 6

Figs. 105-108. Fenestella vestita
105. Habit sketch 106. Stroma 107. Ascus 108. Ascospore

Figs. 109-111. Fenestella rostrata
109. Perithecia 110. Ascus 111. Ascospore

Figs. 112-115. Fenestella ulmicola
112. Habit sketch 113. Stroma 114. Ascus 115. Ascospore

Figs. 116-119. Valsa modesta
116. Habit sketch 117. Stroma 118. Ascus 119. Ascospore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SEED CHARACTERS OF SELECTED PLANT FAMILIES

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ABSTRACT

Seed characteristics of the following plant families are summarized: Araceae, Commelinaceae, Juncaceae, Iridaceae, Orchidaceae, Ulmaceae, Moraceae, Cannabinaceae, Urticaceae, Phytolaccaceae, Arizoaceae, Portulacaceae, Ranunculaceae, Papaveraceae, Fumariaceae, Capparidaceae, Saxifragaceae, Geraniaceae, Hypericaceae, and Violaceae. External characteristics as well as gross internal morphology are characterized and representative types illustrated. Distinguishing characteristics are summarized in the key.

INTRODUCTION

The identification of unknown seeds is difficult and frequently impractical. There are no organized treatments comparable to botanical manuals in which plants may be identified. Usually the only way one can track down an unknown is to look at seeds in a herbarium or check pictures of seeds. Such generalized searching is extremely time consuming and is not invariably rewarded with success.

The possibility of identifying an unknown seed may be materially increased if it can be initially placed in the correct family. Isely's (20) investigations have suggested that it is practical to determine seeds on a family basis. It must be remembered, however, that there are far fewer characters available for study than when dealing with an entire plant. Therefore, ease and accuracy of determinations are limited.

Isely (20) studied seed characters of seventeen of the more important families. The present paper, including twenty additional families, continues these investigations.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Dr. Duane Isely for suggestion of the problem and advice during the course of the investigations, and for guidance and criticism in preparation of the manuscript. The writer also wishes to thank Dr. Richard Pohl for the use of the Iowa State College Herbarium from which seeds were collected.

REVIEW OF LITERATURE

Literature pertaining to taxonomic studies of seeds at the family level is scanty. Such literature is primarily included in treatments of a larger scope, especially taxonomic monographs.

One of the early papers dealing with seeds was by Nägeli (31). He made a systematic review of the distribution of oil and starch in the embryo and endosperm of a great number of seeds. McNair (28) later revised arrangement of the families of Nägeli's paper and formulated a table showing this data for 216 families of seed plants.

Netolitzky (32) summarized the literature for all plant families up to 1926, and prepared anatomical descriptions of the seeds within each family.

One of the standard references for seed identification in the United States is the set of drawings of seeds prepared by Hillman and Henry (19), and included, with some additions, in the Agriculture Handbook No. 30 (46). The latter publication contains keys to species within a limited number of genera, but nothing on the family level. Korsmo (23) prepared a reference work on European weed seeds containing seed descriptions and illustrated by colored plates.

Martin's (27) recent paper on the internal morphology of seeds deals with the relationship of the embryo and nutritive tissue of the mature seed. The plates consist of drawings showing longitudinal and cross sections of seeds and relative size and position of the embryo and endosperm. Martin recognized twelve basic embryo types, most of which included several or many families.

Isely (20) treated seventeen families, chosen to include those seeds most often found in seed analytical work but, in general, the larger and more common in the United States. His paper contains a synopsis of family characteristics in the form of an analytical key as well as a detailed discussion of each family.

The work of LeMaout and Decaisne (25), though early, presents good seed descriptions at the family level and includes many excellent line drawings of seeds. Two German publications that contain descriptive material and line drawings of representative genera are Engler and Prantl's "Die natürlichen Pflanzenfamilien" (9) and Engler's "Das Pflanzenreich" (10). The "North American Flora" (33) possesses some descriptive material concerning the external characteristics of seeds but no illustrations. In many cases, reference is made to published illustrations but these often do not include illustrations of seeds.

North American regional floras, for the most part, contain little in the way of seed description. Abrams (1) and Gleason (15) included many drawings of seeds but their descriptions are scanty. The manuals prepared by Fernald (14) and Small (42), as well as many state floras, contain some descriptive material but are practically devoid of illustrations of seeds.

TERMINOLOGY

The word "seed" may be used in more than one way. Morphologically, a seed is a matured ovule. Ordinarily, a seed consists of an embryo, stored nutritive material, and a seed coat.

In agricultural usage, the word seed is most frequently employed in a functional sense. Any embryo-containing unit capable of developing into a plant is called a seed. In many cases, this structure may include pericarp tissue (as in one-seeded fruits).

In the development of an ovule, the nucellus (megasporangium) begins as a small protuberance on the placenta. As it develops, the integuments are initiated and grow out beyond the nucellus, leaving a narrow passageway, the micropyle. The ovule is usually borne on a short stalk, the funiculus. The basal part of the ovule, at the origin of the nucellus and integuments, is the chalazal area.

The ovule, when mature, may be in one of several positions; this position is consistent for any given species. It may be orthotropous (erect or straight), believed to be the most primitive type; campylotropous (curved), a relatively uncommon form; or anatropous (inverted), the most common type.

The hilum is a scar which indicates the point of attachment of the seed to the funiculus. In the erect ovule, the micropyle is opposite the hilum. In the inverted ovule, the micropyle is adjacent to the hilum and the funiculus is partly attached to the outer integument. This may result in a discernible ridge or line, the raphe. In one-seeded fruits, there is an area functionally analogous to the hilum which, in the present paper, is designated as the scar-area.

Double fertilization is typical of angiosperms. Of two male nuclei, one unites with the egg, and through further development produces the embryo. The other male nucleus, in most cases, unites with the two polar nuclei of the embryo sac, thus forming a triploid nutritive tissue, the endosperm. The endosperm is abundant in many kinds of seeds as a food-storage tissue; in others, it is largely absorbed by the embryo in the course of development.

The nucellus is usually destroyed during maturation of the seed. However, in the Centrospermae, it persists, forming the nutritive tissue, perisperm. In this case, the endosperm is reduced to a thin sheath surrounding the radicle of the embryo, or is lacking.

The embryo possesses one or two seed-leaves or cotyledons. Below the cotyledon(s) is a stem-like portion, the hypocotyl. At the base of the hypocotyl is the primary root or radicle, the tip of which is always directed toward the micropyle. The origin of the radicle cannot be determined externally. Such a determination is possible, usually, only by microscopic examination of prepared sections. Above or between the cotyledon(s) is the primary shoot or bud called the plumule. This is usually the least developed of the four parts of the embryo.

As the seed matures, the integument or integuments undergo changes, becoming the seed coat. Usually, a part of the inner layer of the integument is absorbed by the endosperm or embryo.

In the descriptive portion of this paper, two terms are used with reference to embryo position. Basal designates a position near the hilum or scar-area. An axile embryo is one surrounded by endosperm and aligned with the longer dimension of the seed.

MATERIALS AND METHODS

Seeds examined were selected from the seed herbarium of the Iowa State College Seed Laboratory and from plant specimens of the Iowa State College Herbarium. As examination was limited to plant material from the United States, it was possible to sample nearly all native genera of the families included.

Seeds were examined superficially for shape, the nature of the surface, and positional relationship of the hilum, raphe, and micropyle to the extent that these structures were discernible. Observations were made under a stereoscopic microscope.

Sectioning or dissecting the seed (or one-seeded fruit) was necessary to determine its internal structure. Prior soaking of the seed was usually necessary to obtain a good section. The first section was longitudinally through the hilum and raphe if the latter was present. If this section proved to display the embryo to good advantage, a cross section was also made. These sections are shown in the plates.

The protective layers were examined with respect to origin, that is, whether the seed coat alone or seed coat plus pericarp was present, thickness, and number of evident layers.

The nutritive tissue was examined with regard to abundance, gross morphological structure, texture, and position relative to the embryo. It was tested to determine the presence of starch or oil as the reserve food. A dilute I-KI solution was used to test for starch. A bit of the endosperm was scraped off and a drop of the solution applied. A positive test was shown by a violet to dark blue color. Sudan III solution was used to determine the presence of oil. Seed material was scraped off and soaked in the solution. If oil is present it will show up, usually as red-stained droplets. The staining was observed under a stereoscopic microscope.

The embryo was studied with respect to size, conformation within the seed, and positional relationship to external markings. With twisted or curved embryos, it was desirable to unfold the parts to determine their relationship.

FAMILY SYNOPSIS

1. Embryo with one cotyledon (absent in Orchidaceae).
    2. Endosperm present.
        3. Embryo cylindrical, more than one-half the length of the endosperm.
            4. Endosperm starchy, grainy; seed coat not distinctly two-layered. . . . . ARACEAE (in part), p.655

4. Endosperm not starchy, hard, horny; seed coat distinctly two-layered, outer layer often spongy. . . . . IRIDACEAE, p.657
3. Embryo not cylindrical, less than one-half the length of the endosperm.
5. Embryo dumbbell-shaped, located under a disc-like callosity (embryotega); seed coat not distinctly two-layered; seed neither tailed nor carunculate. . . . . . COMMELINACEAE, p.656
5. Embryo ovoid, not under an embryotega; seed coat distinctly two-layered; seed often tailed or carunculate. . . . . JUNCACEAE, p.657
2. Endosperm not evident on gross inspection.
6. Seeds extremely minute, microscopic; seed coat only one cell layer thick. . . . ORCHIDACEAE, p.660
6. Seeds larger; seed coat thick, more than one cell layer. . . . . ARACEAE (in part), p.655
1. Embryo with two cotyledons.
7. Embryo filling entire seed; a separate nutritive tissue not evident on gross inspection.
8. Embryo straight.
9. Embryo cylindrical; seeds free. HYPERICACEAE, p.678
9. Embryo spatulate; seed enclosed in samara. . . . . ULMACEAE (Ulmus), p.661
8. Embryo folded. . . . . GERANIACEAE, p.677
7. Embryo not filling entire seed; a separate nutritive tissue evident.
10. Embryo peripheral; nutritive tissue (perisperm) hard, grainy; seeds often lenticular, rounded, or reniform.
11. Seeds lenticular; 2 mm or more in diameter. . . . . PHYTOLACCACEAE, p.668
11. Seeds reniform or deltoid; less than 2 mm in longest dimension.
12. Cotyledons firm; seeds usually reniform. . . . . PORTULACACEAE, p.669
12. Cotyledons soft, fleshy; seeds flattened-reniform to deltoid. . . . . . . AIZOACEAE, p.668
10. Embryo not peripheral; nutritive tissue usually soft, not grainy; seeds not lenticular.
13. Seed enclosed in persistant pericarp (achene or drupe).
14. Pericarp hard, bony, thick. ULMACEAE (Celtis), p.661
14. Pericarp neither hard nor bony, may be brittle.
15. Embryo small, less than one-fourth the length of the copious endosperm. . . . . RANUNCULACEAE (in part), p.670
15. Embryo large, forming the bulk of the seed; endosperm sparse.
16. Embryo straight, spatulate. URTICACEAE, p.665
16. Embryo bent, variously shaped.

17. Embryo spiral-shaped . . . CANNABINACEAE (Humulus), p. 664
17. Embryo not spiral-shaped.
18. Cotyledons surrounded by endosperm. . . . . MORACEAE (Morus), p. 664
18. Cotyledons not surrounded by endosperm.
19. Cotyledons edgewise to the radicle; most of the endosperm at the tip and side of the cotyledons, none between the radicle and cotyledons. . . . . MORACEAE (Maclura), p. 664
19. Cotyledons flatwise to the radicle; most of the endosperm between the cotyledons and radicle. . . . CANNABINACEAE (Cannabis), p. 678
13. Seed free, not in a persistent pericarp.
20. Embryo curved, large; endosperm sparse. . . . . CAPPARIDACEAE, p. 674
20. Embryo straight, small to large.
21. Seed bent around an empty center, horseshoe-shaped; embryo in one end. . . . . FUMARIACEAE, p. 671
21. Seed straight or only slightly curved.
22. Embryo spatulate, nearly the length of the seed. . . . . VIOLACEAE, p. 678
22. Embryo cylindrical, short to long.
23. Endosperm firm to hard. . . . . SAXIFRAGACEAE (in part), p. 675
23. Endosperm soft.
24. Endosperm a thin layer; embryo full length of the seed. . . . . SAXIFRAGACEAE (in part), p. 675
24. Endosperm copious; embryo not full length of the seed.
25. Seed coat thin, pliable, easy to cut. . . . . . SAXIFRAGACEAE (in part), p. 675
25. Seed coat relatively thick, or if thin, brittle.
26. Seed coat reticulate. . . . . PAPAVERACEAE (in part), p. 671
26. Seed coat smooth to rough, wrinkled or scaly, not reticulate.
27. Seed coat smooth, with a wide prominent crested raphe. . . . PAPAVERACEAE (Sanguinaria), p. 671
27. Seed coat smooth to rough, without a crested raphe. . . . . RANUNCULACEAE (in part), p. 670

SEED CHARACTERISTICS

Araceae (Plate 1)

General characteristics

Seeds ovoid, cylindrical or somewhat angular, with a terminal hilum. Seed coat thick, coriaceous, with a rough surface. Endosperm absent or abundant. Embryo straight, axile in those seeds with endosperm.

Morphology

The ovules are orthotropous in most genera (anatropous in Calla). They are erect or pendulous, with two integuments. The seed coat is thick and tough. The nucellus is obsolescent.

The endosperm is absent or abundant, grainy, and containing starch. Raphides may be present in the endosperm or the embryo.

In the seeds with endosperm, the embryo is axile, cylindrical (somewhat angular in Acorus), and more than one-half the length of the seed. The radicle tip of the embryo is opposite the hilum, except Calla, in which it is adjacent. In those seeds without endosperm, the embryo is fleshy and fills the seed coat.

External characteristics

The seeds range from irregularly ovoid or cylindrical to long-angular in shape. The hilum is terminal. Ordinarily the seed is without a raphe and has an amorphous integumental tuft at the hilum. The seed coat is variously rough, scratchy, to pitted.

Associated structures

The ovary is superior though sometimes imbedded in the spadix. There are 1–3 locules, with one to many ovules in each. The placentation is various, basal, axile, or apical. The ovary may be rather gelatinous on the inside.

The fruit is a dry, tough or leathery berry, with one to few cells containing one to many seeds. With the addition of water it may become gelatinous on the inside.

Classification by seed characters

The eight indigenous genera of this country can be separated into three groups by seed characteristics. This grouping is consistent with the subfamily classification of Engler and Krause (8).

1. Endosperm absent.
   Tribe Symplocarpeae of the Calloideae, represented by Lysichitum, Symplocarpus, and Orontium.
1. Endosperm present.
   2. Radicle tip of the embryo near the hilum.
      Tribe Calleae of the Calloideae, represented by Calla. This genus is an exception to the general characteristics of the family in that the ovule is anatropous and consequently a raphe is evident on the seed.

2. Radicle tip of the embryo opposite the hilum.
Four subfamilies, represented in this country by Acorus, Arisaema, Peltandra, and Pistia.

Commelinaceae (Plate 1)

General characteristics

Seeds ovoid to angular, the hilum a slit on the flat, lateral face. Seed coat membranous or rigid, usually rough. Endosperm copious, firm, starchy. Embryo small, pulley-shaped or capitate.

Morphology

The ovules are orthotropous with two integuments. The outer integument consists of several cellular layers, the inner, two. The external layer of cells of the outer integument becomes soft and flake-like at maturity.

The seed coat is membranous or rigid, but not tough, and is closely adherent to the endosperm. The nucellus is obsolescent but the endosperm is abundant, starchy, and usually quite firm or hard.

The white embryo is small, pulley- or dumbbell-shaped, or capitate. The radicle is covered by a disk-like callosity, the embryotega.

External characteristics

The seeds are ovoid, angular, peltate- or triangular-flattened. The precise shape is dependent upon the number of seeds in a locule of the fruit. The hilum is a long seam, extending about three-fourths the length of the seed, and lying on the flat, sometimes depressed side of the seed.

The surface of the seed is variable, rough, muricate, ridged, rugose or foveolate, sometimes appearing sugar-coated. The embryotega appears as a lid covering the embryo. Its position may be either lateral or dorsal in relation to the hilum.

Associated structures

The ovary is superior, either sessile or stipitate. There are usually three locules with one to few horizontal ovules in each locule. The placentation is axile.

The fruit is a loculicidal capsule, rarely indehiscent, mostly three-celled, and containing one or two seeds in each locule (4—5 in Tinantia). Occasionally, only one seed is present due to an undeveloped ovule. In this case the seed is more or less ovoid. If several seeds are present, they are crowded with contiguous faces flattened.

Classification by seed characters

The Commelinaceae is usually divided into two subfamilies (Woodson, 50; Bruckner, 5). Seed characteristics substantiate the validity of these groupings. Relative to the ventral position of the hilum, in the Tradescantieae the embryotega is dorsal; in the Commelineae it is lateral.

Juncaceae (Plate 1)

General characteristics

Seeds ovoid, subglobose to fusiform, often tailed at each end, with a terminal hilum. Seed coat thin, two-layered. Endosperm copious, with starch. Embryo small, basal.

Morphology

The ovules are anatropous and have two integuments. The inner integument consists of two cell layers, the outer may be two- to many-layered.

The seed coat is two-layered, the outer layer often forming a loose, membranous, cellular coat that is drawn out at the ends to form a tail-like or caruncluate appendage. The nucellus is present only as a trace.

The firm, starchy endosperm forms the bulk of the seed. The embryo is small, basal, axile, globose, and less than one-half the length of the endosperm.

External characteristics

The seeds are small, cylindrical, spindle-shaped, or subspherical, except for the tail. Seeds of Luzula may have a sectoroid appearance. The hilum is located at one end of the seed.

The seed coat is usually reticulate and roughened. Sometimes the outer coat is loose and colorless, giving the seed a whitish appearance. The inner coat is reddish or brown colored.

Associated structures

The ovary is superior, either unilocular with three parietal placentae, of trilocular with basal placentation. There are three to many ovules.

The fruit is a loculicidal, three-valved capsule containing numerous seeds or (Luzula) three sectoroid seeds.

Classification by seed characters

The two genera found in this country can be separated quite readily.

Juncus. The seeds are small, never more than 1 mm in length, usually with tailed appendages.

Luzula. The seeds are large, mostly 1.3 mm or more in length, usually sectoroid with a distinct raphe at the juncture of the two flattest faces. The seed coat may form a caruncluate appendage at the hilum but is never drawn out into a tail. Vierhapper (47) states that this is the only genus of the family possessing the caruncluate appendage.

Iridaceae (Plate 1)

General characteristics

Seeds globose to somewhat flattened, the hilum at the end of the seed. Seed coat usually rough, thick and spongy, not tough. Endosperm hard or horny, without starch. Embryo cylindrical, axile, over one-half the length of the endosperm.

PLATE 1*

Araceae, Commelinaceae, Juncaceae, Iridaceae, Orchidaceae

Arisaema triphyllum (L.) Schott.
1. Longitudinal section X4.5
2. Cross section X4.5

Commelina communis L.
3. Longitudinal section X7.5
4. Cross section X7.5

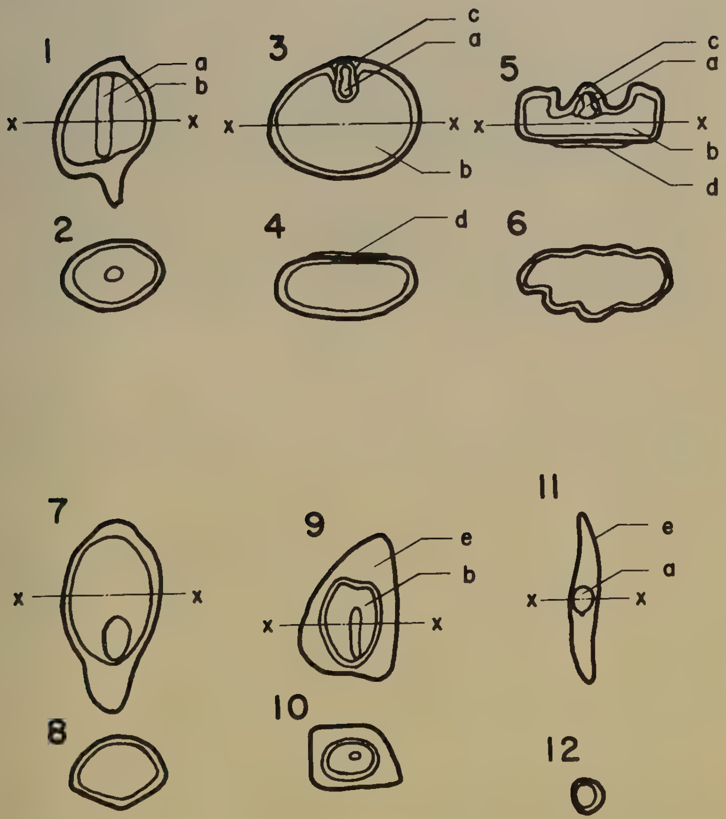
Tradescantia virginiana L.
5. Longitudinal section X9
6. Cross section X9

Luzula campestris (L.) DC.
7. Longitudinal section X19
8. Cross section X19

Iris virginica L.
9. Longitudinal section X3
10. Cross section X3

Cypripedium candidum Muhl.
11. Longitudinal section X21
12. Cross section X21

*a. Embryo. b. Endosperm. c. Embryotega. d. Hilum. e. Seed coat. x--x. Plane of cross section.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Morphology

The ovules are anatropous and have two integuments. The outer is many-layered, the inner two-layered.

The seed coat is distinctly two-layered, the inner thin and closely adherent to the endosperm, the outer thick and sponge-like. The nucellus is obsolescent.

The abundant endosperm is hard or horny, occasionally with small cavities throughout, and contains oil as the reserve food. The embryo is basal, axile, cylindrical, and exceeding one-half the length of the endosperm.

External characteristics

The seeds are subglobose or compressed and rounded. The seed coat is usually rough, sometimes wrinkled or reticulate, occasionally drawn out into a wing. The hilum is at the smaller end or at the juncture of compressed faces. In some instances, a raphe is discernible.

Associated structures

The inferior ovary is mostly three-celled, with axile, biseriate placentae bearing numerous ovules in each cell.

The three-celled capsule is loculicidally dehiscent. The numerous seeds are usually closely arranged in two rows in each locule.

Orchidaceae (Plate 1)

General characteristics

Seeds minute, usually fusiform, with a loose, reticulate seed coat. Endosperm absent; embryo a mass of undifferentiated cells.

Morphology

The anatropous ovules have two integuments, each of which is only one or two cell layers thick. The nucellus disappears early.

The seed coat consists only of the outer layer of cells of the outer integument. These cells lose their protoplasts and the entire layer becomes transparent and appears reticulate.

There is no recognizable endosperm in the mature seed. The embryo is an undifferentiated, ovoid mass of cells. Further development is initiated only after dispersal of the seeds. The suspensor is sometimes persistent, forming a slight beak toward the hilar end of the seed.

External characteristics

The seeds are extremely small, scobicular, or fusiform with a loose seed coat drawn out into tails. The hilum, at the end of a tail, is difficult to discern.

Associated structures

The inferior ovary, frequently long and twisted, is composed of three connate carpels forming a single locule. Each carpel possesses a biseriate, parietal placenta bearing numerous ovules.

The capsular fruit dehisces by 3–6 hygroscopically sensitive valves which remain apically connate. It may contain upwards of a million seeds.

Ulmaceae (Plate 2)

General characteristics

Seeds globose or oblong-flattened, persistent within a samara or drupe. Seed coat brown, thin and papery, with minute reticulations. Endosperm present or absent. Embryo straight or folded.

Morphology

The anatropous ovules are pendulous, with two integuments. The hilum of the seed is opposite the scar-area. The seed coat is thin, papery, and sometimes adherent to the endocarp in the Celtideae. The nucellus is not evident in mature seeds.

Endosperm is present in the Celtideae, absent in the Ulmeae. Where present, it is localized near the radicle tip and between folds of the cotyledons.

In the Ulmeae, the embryo is straight, with flat cotyledons. In the Celtideae, it is curved, with folded, sinuous cotyledons. The radicle tip is opposite the scar-area of the samara or drupe.

External characteristics

Seeds of the Celtideae are persistent within the endocarp of the drupe. This unit is nearly spherical, with a scar-area at the terminus of the vein-like reticulations on the surface. Seeds of the Ulmeae are oblong-flattened, and persistent in the samara which fits loosely around the seed.

Associated structures

The superior ovary is bicarpellate, unilocular, and contains a single pendulous ovule.

The fruit of the Celtideae is a drupe with a hard, bony, pitted or roughened endocarp which always encloses the spherical seed. In the Ulmeae, the fruit is a samara, in which the seed is usually persistent.

Classification by seed characters

The seed characteristics are consistent with the separation of the family into two tribes by Fernald (14).

Celtideae. Seeds globose, with a curved embryo, found in the bony endocarp of the fruit.

Ulmeae. Seeds flattened, with a straight embryo, usually found in the samara.

PLATE 2*

Ulmaceae, Moraceae, Cannabinaceae, Urticaceae

<u>Ulmus</u> <u>americana</u> L.
1. Longitudinal section parallel to flat side X3
2. Cross section X3

<u>Celtis</u> <u>occidentalis</u> L.
3. Section through radicle, pericarp and seed coat removed X4.5
4. Section across radicle, pericarp and seed coat removed X4.5

<u>Morus</u> <u>rubra</u> L.
5. Longitudinal section X12
6. Cross section X12

<u>Cannabis</u> <u>sativa</u> L.
7. Longitudinal section X6
8. Cross section X6

<u>Humulus</u> <u>japonicus</u> Sieb. and Zucc.
9. Longitudinal section X6
10. Cross section X6

<u>Laportea</u> <u>canadensis</u> (L.) Wedd.
11. Longitudinal section parallel to flat side X7.5
12. Cross section X7.5

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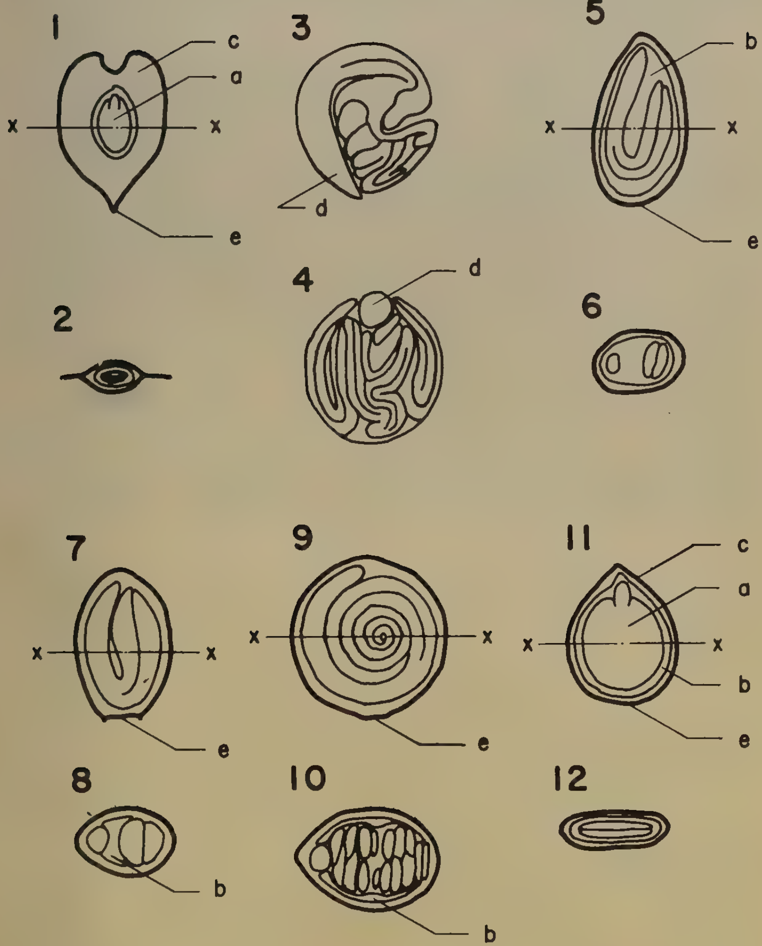
*a. Embryo. b. Endosperm. c. Pericarp. d. Radicle. e. Scar-area. x--x. Plane of cross section.


1
c
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x
e
2
3
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4
d
5
b
x
x
e
6
7
x
x
e
8
b
9
x
x
e
10
b
11
c
a
x
x
b
e
12

Moraceae (Plate 2)

General characteristics

Seeds oblong, slightly flattened, borne in an indehiscent fruit (achene). Seed coat thin, papery, brown. Endosperm abundant to sparse. Embryo bent, cotyledons flat.

Morphology

The anatropous ovules are ordinarily pendulous, with two integuments. The seed coat is thin, papery, and usually free from the relatively heavy wall of the achene. The nucellus may be present, but only as a trace.

The endosperm is fleshy, abundant or sparse. The embryo is bent. In Morus, the cotyledons lie flatwise relative to the radicle and endosperm is present about the embryo between the radicle and the cotyledons. In Maclura, the cotyledons are turned edgewise to the radicle and the endosperm is entirely external. The radicle tip is near the hilum which is opposite the scar-area.

The seed is ordinarily quite loose in the enclosing pericarp.

External characteristics

The achenes are usually oblong, somewhat flattened, with the scar-area at one end. The remnants of the style are indicated by a roughened appearance near the opposite end but not terminal. There is a wide seam from end to end on each side of the achene.

The surface may be dull or shiny and varies from light to dark tan.

Associated structures

The superior ovary is two-carpellate, with one locule containing the solitary pendulous ovule. The fruit is an achene, often buried in the succulent calyx, and appearing drupe-like.

Cannabinaceae (Plate 2)

General characteristics

Seeds subglobose, usually enclosed in the pericarp, with thin seed coat. Endosperm present in minor amounts, soft. Embryo bent or coiled.

Morphology

The pendulous ovules are anatropous, with two integuments. The seed coat is very thin, sometimes adherent to the pericarp. The hilum is opposite the scar-area.

The sparse endosperm is quite soft and localized between the radicle and cotyledons in Cannabis. In Humulus, the endosperm is a thin sheath surrounding the embryo.

The embryo in Cannabis is bent double, with the cotyledons placed flatwise to the radicle. In Humulus, on the other hand, the cotyledons are coiled. Basally, and for one complete circle, one lies outside the other; terminally, they separate, forming two adjacent coils.

External characteristics

The achenes are subglobose, somewhat flattened between the scar-area and the terminal vestiges of the style. The scar-area is prominent in Cannabis, whereas the style-area is prominent in Humulus. Humulus seeds are frequently surrounded by an additional, close-fitting, thin membrane.

The basic color is tan or gray, with mottling on most seeds. The surface may be dull or somewhat shiny.

Associated structures

The bicarpellate ovary is superior, with a single locule possessing a solitary, pendulous ovule. The fruit is a subglobose or somewhat laterally-flattened achene. It is usually covered by the persistent perianth, and often accessory bracts.

Classification by seed characters

The two genera in this country are easily distinguished by the characteristic embryo as above described.

Urticaceae (Plate 2)

General characteristics

Seeds oblong-flattened, usually enclosed in the pericarp, hilum adjacent to scar-area. Endosperm fleshy, oily. Embryo spatulate, straight.

Morphology

The orthotropous ovules have two several-layered integuments. The thin, membranous seed coat is sometimes adherent to the pericarp. The nucellus disappears at maturity.

The endosperm is peripheral, fleshy, with oil as the reserve food. The embryo is straight, axile, with flattened, oblong cotyledons. The radicle is superior, opposite the hilum which is just under the scar-area.

External characteristics

The oblong-flattened achenes are usually dull, brownish, with a rough surface. The scar-area is on the broader end with the style forming a beak at the narrow end. Sometimes the achene is asymmetrical, the scar-area and style not being at the extreme ends.

Associated structures

The ovary is superior or partially inferior, of one carpel, with one locule and contains a single, erect ovule. The fruit is an achene, often invested by the persistent perianth.

PLATE 3*

Phytolaccaceae, Aizoaceae, Portulacaceae, Ranunculaceae

Phytolacca americana L.
1. Section parallel to face X7.5
2. Cross section X7.5

Mollugo verticillata L.
3. Section parallel to face X38
4. Cross section X38

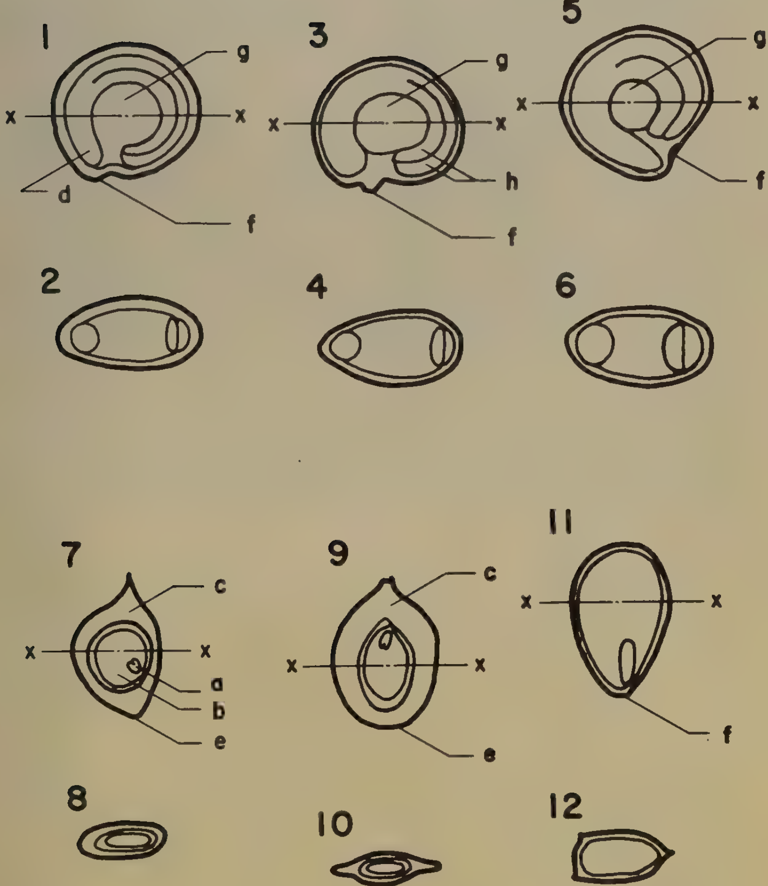
Portulaca oleracea L.
5. Section parallel to face X30
6. Cross section X30

Ranunculus pensylvanicus L.
7. Longitudinal section X7.5
8. Cross section X7.5

Anemone canadensis L.
9. Longitudinal section X4.5
10. Cross section X4.5

Nigella damascena L.
11. Longitudinal section X9
12. Cross section X9

*a. Embryo. b. Endosperm. c. Pericarp. d. Radicle. e. Scar-area. f. Hilum. g. Perisperm. h. Cotyledons. x--x. Plane of cross section.


1
3
5
g
x
d
f
h
2
4
6
7
9
11
c
a
b
e
8
10
12

Phytolaccaceae (Plate 3)

General characteristics

Seeds lenticular, usually 2–3 mm in diameter, with a marginal hilum. Seed coat black, shiny, and smooth. Embryo peripheral, surrounding the nutritive tissue (perisperm).

Morphology

The ovules are campylotropous. There are two integuments which in most genera are each two-layered. The outer integument of Phytolacca is thicker. The seed coat is thin and brittle.

The nutritive tissue is centrally placed perisperm (of nucellar origin, generally characteristic of the Centrospermae). The reserve food is starch which is true for most of the order.

The embryo is peripheral, forming a ring which almost surrounds the perisperm. The cotyledons are usually slightly longer than the rest of the embryo. One cotyledon is outside the other in the flat plane of the seed. The outer sometimes overlaps the edges of the inner cotyledon. There is some convolution of the cotyledons of Rivina.

External characteristics

The seeds are lenticular, with a black, smooth, shiny surface. The hilum is marginal, close to a slight notch in the rim of the seed. Sometimes there is a small mass of amorphous tissue filling the notch. The seeds are fairly large compared to those in related families.

Associated structures

The ovary, in our genera, is superior and composed of one to several carpels. The carpels are usually connate, with one ovule in each carpel. Placentation is basal or axile. The fruit is usually a berry.

Aizoaceae (Plate 3)

General characteristics

Seeds flattened-reniform or deltoid. Seed coat dark, often somewhat ridged. Perisperm centrally placed, hard, with starch. Embryo peripheral, cotyledons fleshy.

Morphology

The ovules are campylotropous, with two integuments each of which is two-layered. The seed coat is thin and rather brittle. The abundant perisperm is hard and translucent, sometimes grainy-white, and starchy. Upon wetting it becomes very soft.

The embryo is peripheral, completely surrounding the perisperm in most genera. In Mesembryanthemum and Tetragonia it does not form a complete circle. The soft, fleshy cotyledons lie with one placed outside the other in the flat plane of the seed.

External characteristics

Seed shape is dependent on the manner in which the embryo is bent and varies from flattened-reniform to deltoid or angular, measuring less than 2 mm in the longest dimension. The surface is dull and dark, occasionally shiny, usually marked with ridges or tubercules in concentric rows. In some instances, the funiculus is persistent on the margin of mature seeds.

Associated structures

The ovary ranges from inferior in Tetragonia to superior in Mollugo. In most of the genera it is partly inferior. The ovary has one (rarely) to several locules with one to several ovules in each locule. Placentation is axile.

The fruit is a capsule in those genera with a superior or mostly superior ovary. Dehiscence is loculicidal or circumscissile. The fruit derived from an inferior ovary is, on the other hand, nut- or berry-like and indehiscent.

Portulacaceae (Plate 3)

General characteristics

Seeds mostly round-reniform, lenticular, small, with a marginal hilum. Perisperm copious, centrally placed, starchy. Embryo peripheral, horseshoe-shaped, with firm cotyledons.

Morphology

The ovules are campylotropous. The two integuments are each two-layered. The seed coat is thin, delicate and brittle. The central perisperm is abundant, hard and translucent, starchy.

The peripheral embryo is horseshoe-shaped or completely surrounds the perisperm. The cotyledons are firm, usually with one outside the other in the flat plane of the seed. In Claytonia, they are turned at right angles, one placed on top of the other in the flat plane of the seed.

External characteristics

The seeds are mostly round-reniform, compressed, somewhat lenticular, usually with a marginal tip or notch at the hilum which may give the seed a tapered appearance. The seed coat is generally dark and shiny, in some instances dull with a tuberculate surface. Some seeds are strophiolate.

Associated structures

The ovary is superior (semi-inferior in Portulaca), one-celled with 2–3 united carpels. The placentation is basal or central. The fruit is a capsule with circumscissile dehiscence (Portulaca, Lewisia, Oreobroma) or loculicidally dehiscent by 2–3 apical valves.

Ranunculaceae (Plate 3)

General characteristics

"Seeds" of two general types: (1) flattened achenes with a well-developed pericarp and a thin seed coat, (2) true seeds (produced in follicles or berries) generally ovoid, with a smooth or rough, usually thick and brittle seed coat.

Endosperm abundant, soft-fleshy. Embryo very small, soft.

Morphology

The ovules are anatropous, horizontal (in follicular fruits), or (in the one-seeded fruits) pendulous with a dorsal raphe or erect with a ventral raphe. There are two integuments. The seed coat of the true seed is crustaceous, whereas in the achene it is thin and pliable.

The endosperm is the major bulk of the seed. It is soft and opaque-white to gray, with a watery-fleshy texture. The reserve food is of an oily nature.

The embryo is relatively small, often the same color and texture as the endosperm and therefore difficult to distinguish. It is usually less than one-tenth the length of the seed but is slightly longer in some species of Ranunculus and Nigella. In Ranunculus, the embryo, hilum, and scar-area are adjacent. In other genera producing achenes, the seed is pendulous and the hilum and embryo are opposite the scar-area.

External characteristics

The achenes are usually flattened and ovate, sometimes angular. They are usually tipped by the persistent style with the scar-area on the other end. Seeds produced in follicles are ovoid or somewhat flat and oblong, ranging from smooth-rounded to angular. For the most part, such seeds in follicles have a prominent raphe which, however, if the seed coat is wrinkled, may be difficult to see. The hilum is at the end of the longer dimension of the seed.

Associated structures

Carpels many, separate (united in Nigella), superior and containing one to many anatropous ovules. The ovules, if numerous, are in two rows arising from a parietal placenta.

The fruit is various, one-seeded (an achene), follicular, baccate (Actaea, Hydrastis), or capsule-like (Nigella).

Classification by seed characters

Wettstein (48) and many other phylogenists treat the family as comprising three tribes, the Helleboreae, Anemoneae, and Paeonieae. Paeonia is sometimes placed in a separate unigeneric family. Its seeds are relatively large and have a thick, tough seed coat.

The Anemoneae is characterized by a uniovulate pistil bearing a single seed with a thin and pliable seed coat. The achenes can be further separated into two groups. In Ranunculus, the seed is erect, the hilum located just beneath the scar-area. In other genera, such as Anemone, the seed is pendulous, the hilum located under the beak of the style and opposite the scar-area.

The Helleboreae have a multiovulate pistil and seeds with a thick and crustaceous coat. The seeds can be separated into groups parallel to those of the different fruit types. In Nigella (fruit capsule-like), the embryo is about one-third the length of the seed whereas in the remainder of the tribe it is considerably shorter. The fruit of Actaea and Hydrastis is berry-like and indehiscent. The follicular fruits of the remaining genera bear small, free seeds with a reduced embryo.

Papaveraceae (Plate 4)

General characteristics

Seeds globose to subreniform, smooth to reticulate. Seed coat dark, dull to shiny. Endosperm abundant, oily. Embryo small, basal, axile.

Morphology

The ovules are anatropous, with two integuments. The integuments are at first two-layered; subsequently, the outer becomes thicker at the micropyle and the raphe, and the inner ultimately possessed of three layers. The nucellus is obsolescent. The seed coat is brittle, either thick or thin.

The endosperm is soft, watery-fleshy, abundant, and contains oil as the reserve food. It is usually an opaque-white. The embryo is less than one-half the length of the seed and may be very small. It is basal, axile, and in some cases, slightly curved. The cotyledons in Eschscholtzia are divergent while in the other genera they are together.

External characteristics

The seeds range in shape from globose to subreniform, being slightly larger on one end than the other. Some are crested due to a continued growth of the cellular material of the raphe. The seed coat is usually dark, dull, reticulate (smooth and shiny in Sanguinaria). The hilum is near the smaller end of the more globose seeds. On the reniform-shaped seeds, the hilum is at the base of the raphe on the concave surface. The hilum is difficult to distinguish on some seeds due to the densely reticulated surface.

Associated structures

The ovary is superior and one-celled or falsely two-celled. It is compound, with two or more carpels, and contains numerous ovules on two or more parietal placentae.

The fruit, in most cases, is a dehiscent capsule. In Platystemon, it is composed of several linear, few-seeded pods which are indehiscent, but at length break transversely between the seeds.

Fumariaceae (Plate 4)

General characteristics

Seeds rounded-reniform. Seed coat black, shiny, smooth or rough. Endosperm copious, soft, oily. Embryo small.

PLATE 4*

Papaveraceae, Fumariaceae, Capparidaceae, Saxifragaceae

Roemeria refracta (Stev.) DC.
1. Longitudinal section X18
2. Cross section X18

Corydalis aurea Willd.
3. Section parallel to face X12
4. Cross section X12

Cleome lutea Hook.
5. Section parallel to face X7.5
6. Cross section X7.5

Mitella diphylla L.
7. Longitudinal section X15
8. Cross section X15

Penthorum sedoides L.
9. Longitudinal section X38
10. Cross section X38

Ribes missouriense Nutt.
11. Longitudinal section X9
12. Cross section X9

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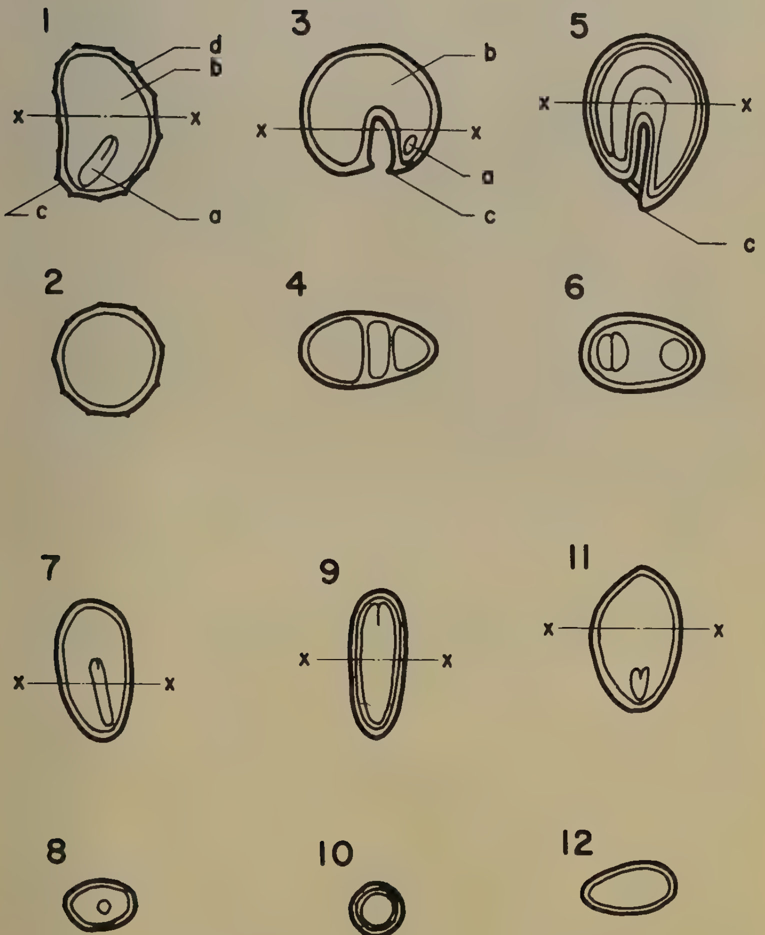
*a. Embryo. b. Endosperm. c. Hilum. d. Seed coat. x--x. Plane of cross section.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3
b
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x
a
c
5
x
x
c
2
4
6
7
x
x
9
x
x
11
x
x
8
10
12

Morphology

The ovules are anatropous or campylotropous (Fumaria). There are two integuments which, in most genera, develop into a thick, brittle seed coat; contrariwise, the seed coat in Fumaria is thin and pliable.

The abundant, oily endosperm is soft, watery-fleshy in texture, and usually yellow colored. The small embryo is located near the hilum. It is sometimes difficult to distinguish both cotyledons.

External characteristics

The seeds are rounded-reniform and relatively uniform in size, ranging from 1.5 to 2 mm in the longest dimension. The hilum is not in the notch but on the adjacent end. The seed coat is usually black, shiny, smooth or reticulate, and in some genera, crested.

Associated structures

The superior ovary consists of two carpels forming one locule. The placentation is parietal with one to several ovules. The fruit is either a dehiscent, several-seeded capsule or an indehiscent, one-seeded nutlet.

Classification by seed characters

The seed characteristics of the genera in this country are consistent with the tribal separation of the group by Fedde (13). The Fumarieae, represented by Fumaria, is characterized by an indehiscent, one-seeded fruit; the seed coat is reduced and thin. In the Corydaleae, containing the other genera, the seeds are free and the seed coat thick.

Capparidaceae (Plate 4)

General characteristics

Seeds flattened-globose to obovoid, conduplicate. Seed coat light or dark, smooth to rough. Endosperm sparse, soft, oily; embryo large, curved.

Morphology

The anatropous ovules are pendulous or horizontal, with two distinct integuments. The seed coat is thick, not brittle, and in two layers, the inner usually the thicker.

The endosperm is sparse, soft and fleshy (not watery), and oily. The bulk of the endosperm is localized near the center of the seed but also extends as a thin layer surrounding the embryo.

The embryo is large, curved, and extends the full curved length of the seed. The cotyledons lie one outside the other in the flatter plane of the seed and are about half the length of the embryo.

External characteristics

The seeds are conduplicate, the folding resulting in a flattened-globoid or obovoid shape with a slight extension at the hilar end of the seed. The notch at the bend of the seed is usually covered with a very thin membrane. The seed coat may be smooth and shiny or variously roughened, reticulate or tuberculate. In color it varies from light tan to dark red.

Associated structures

The superior ovary is borne on a short or long gynophore. The two carpels form one cell with two parietal placenta. There may be two to many ovules.

The capsule is dehiscent by two valves separating from a frame-like placenta, the replum. In Wislizenia and Oxystylis, each valve closely contracts on its single seed and is deciduous with it in a nut-like fashion.

Classification by seed characters

The genera found in this country belong to the subfamily Cleomoideae, one of the eight as recognized by Pax and Hoffmann (35). There are three general groups into which our seeds can be separated:

1. Seeds in a deciduous valve, Wislenzia, Oxystylis.
2. Seeds free, large (7-8 mm) and smooth, Isomeris.
3. Seeds free, small (2-3 mm) and roughened, other genera.

Saxifragaceae (Plate 4)

General characteristics

Seeds various, small to large (0.5 to 7 mm long), usually angular. Seed coat thin, smooth to rough. Endosperm copious to sparse, firm to soft-fleshy, oily. Embryo basal or axile and straight, short to long.

Morphology

The ovules are anatropous, pendulous, horizontal or ascending. Two integuments are the general rule with the exception of the subfamily Hydrangeoideae, in which there is only one. The thin, pliable seed coat is not brittle.

The oily endosperm is abundant in most groups (sparse in Parnassioideae and Penthoroideae), soft-fleshy (but firm in Ribesioideae). The straight, cylindrical embryo is short and basal or axile up to the full length of the seed. The cotyledons are relatively short.

External characteristics

The seeds are variously shaped, usually angular or somewhat rounded, with the hilum at the end of the longer dimension of the seed. The seed coat is variously smooth to figured or rough. The raphe is prominent in some genera. Occasionally the loose testa is drawn out into short tails.

Associated structures

The ovary is superior, semi-inferior, or inferior. There are two to several carpels which are free or more or less united and contain numerous ovules on axile or parietal placentae. The fruit may be a capsule, berry, or follicle.

Classification by seed characters

The many genera have been separated into groups and six of these are represented in this country. Some authors, e.g., Small (42), Britton (4), Coville and Britton (7), Rydberg (38, 39, 40), and Small and

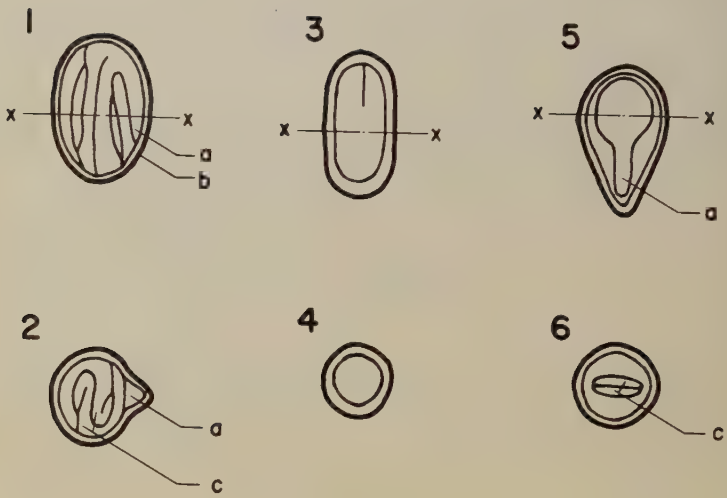

PLATE 5*

Geraniaceae, Hypericaceae, Violaceae

Geranium bicknelli Britt.
1. Longitudinal section X12
2. Cross section X12

Hypericum perforatum L.
3. Longitudinal section X18
4. Cross section X18

Viola papilionacea Pursh.
5. Longitudinal section X12
6. Cross section X12

*a. Radicle. b. Hilum. c. Cotyledons. x--x. Plane of cross section.

Rydberg (43), elevate these groups to family status. This paper follows the subfamily arrangement of Fernald (14) and Engler (11).

The seeds can be segregated into three categories by the relationship of the embryo length to the total length of the seed, and endosperm texture.

1. Saxifragoideae, Hydrangeoideae, Escallonioideae. Embryo half or more than half the length of the seed; endosperm copious, soft-fleshy.
2. Parnassioideae, Penthoroideae. Embryo the full length of the seed; Endosperm sparse, a thin layer around the embryo, soft-fleshy.
3. Ribesioideae. Embryo less than half the length of the seed; endosperm firm to hard.

Geraniaceae (Plate 5)

General characteristics

Seeds obovoid to spindle-shaped or tapered. Seed coat two-layered, reticulate or smooth. Endosperm not evident. Embryo bent, cotyledons plicate.

Morphology

The ovules are anatropous. The integuments are distinct, developing into a seed coat that is two-layered, but thin and not brittle. The endosperm is not evident on gross inspection, but sometimes a thin layer is apparent around the radicle in immature seeds.

The embryo is bent, the radicle tip near the hilum. The plicate cotyledons are twice folded, fitting together in a corrugate-like manner (see Plate 5). The mature embryo is firm and hard.

External characteristics

The seeds are obovoid to spindle-shaped or tapered-flattened toward the hilar end. The hilum is lateral but contiguous to the smaller end of the seed. A raphe is prominent, extending from the hilum to the chalaza. Opposite the raphe, a lateral ridge indicates the position of the radicle. The seed coat is reticulate (relatively smooth in *Erodium*) or pitted.

Associated structures

The superior ovary is composed of five carpels. Each carpel contains two ovules on an axile placenta. Only the upper ovule develops into a seed, the lower aborting.

The capsular fruit splits apart elastically from the central axis, each carpel containing a single seed. The seed usually remains within the carpel.

Classification by seed characters

Knuth (22) divided the family into five tribes. All our genera belong to the Geranieae in which the carpels split apart elastically at maturity. This type of dehiscence is not found in the other tribes.

The three genera occurring in this country can generally be separated by seed shape. Erodium seeds are spindle-shaped, tapering to the small end at the chalaza. The seeds of Geranium are of an obovoid form and scarcely tapered. Pelargonium (an introduction) seeds are the largest, flattened, and tapered at the end.

Hypericaceae (Plate 5)

General characteristics

Seeds cylindrical, small. Seed coat relatively thick and reticulate. Endosperm not evident. Embryo the shape of the seed, straight.

Morphology

The ovules are anatropous and horizontal. Of the two integuments, the inner becomes many-layered and thickened, the outer remaining two-layered. The seed coat is distinctly two-layered, thick and tough.

Endosperm is not evident in the mature seed. The soft embryo is straight, filling the seed coat, and assuming the shape of the seed. The cotyledons are quite short and half-cylindrical.

External characteristics

The seeds are cylindrical or pellet-shaped, nearly straight and small (mostly under 1 mm in length). The seed coat is distinctly reticulate. The reticulations, limited to the outer layer of the seed coat, are easily scraped off. The raphe is a fine line extending the entire length of the seed. In some species, a low wing may be present.

Associated structures

The ovary is superior, composed of 2–5 carpels forming a single locule or each carpel forming a locule. Placentation is parietal in the one-celled or partially septate ovaries, axile in others. The ovules are numerous and, in many species, are in rows in each cavity of the ovary.

The fruit is a many-seeded septicidal capsule.

Violaceae (Plate 5)

General characteristics

Seeds obovoid to subglobose. Seed coat smooth, shiny, brownish. Endosperm copious, soft-fleshy, oily. Embryo axile, spatulate.

Morphology

The anatropous ovules have two integuments, each of which is usually three-layered. The seed coat is hard and brittle at maturity. The copious endosperm is soft-fleshy and oily.

The embryo is axile, extending almost the full length of the seed. The lower part of the embryo is cylindrical, extended in Viola, shorter in Hybanthus. The expanded, flattened cotyledons lie face to face, their edges nearly contiguous to the seed coat. The edges lie nearly in the plane of a longitudinal cut through the raphe.

External characteristics

The seeds are obovoid to subglobose, 1–3 mm long in Viola, and up to 5 mm in length in Hybanthus. The hilum is at the smaller end. A raphe extends from the hilum to the other end of the seed. The seed coat, usually some shade of brown, is ordinarily darker in the chalazal area. The seed may be carunculate.

Associated structures

The superior ovary is tricarpellate and unilocular. The placentation is parietal with two to many ovules on each placenta. The fruit is a loculicidal capsule. After opening, each valve dries and folds together longitudinally on the placenta. This forces out the seeds and sometimes actually projects them for a short distance.

Classification by seed characters

The two genera of this country belong to the tribe Violeae, as segregated by Melchior and Becker (29). The seeds are separable by several characters. Those of Viola are small (under 3 mm long), usually dark in color, with a longer radicle and narrower cotyledons. Hybanthus seeds are large (over 3 mm in length), usually a light tan, with a short radicle and wider cotyledons.

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